Global Models, World Futures, and Public Policy: A Critique

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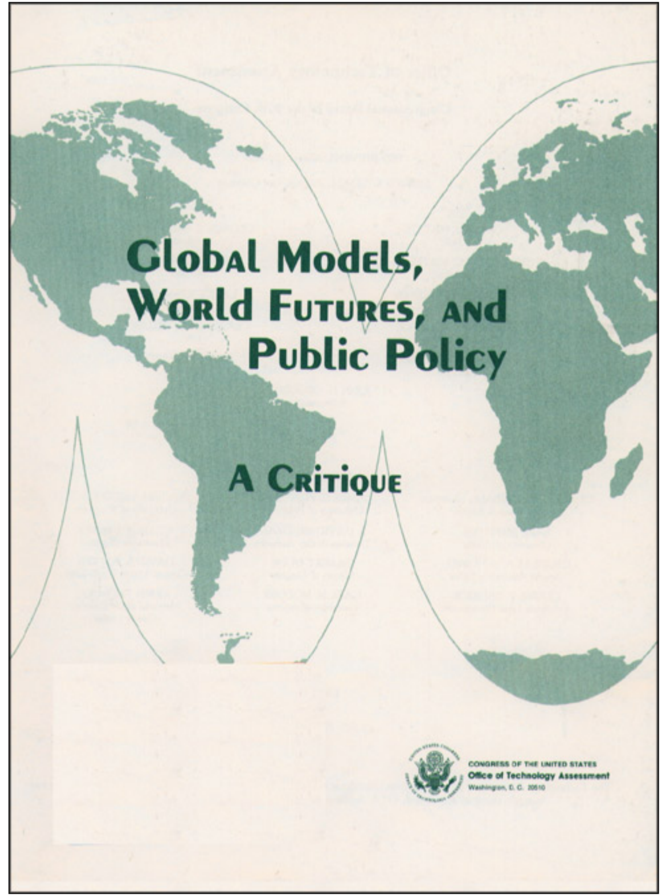

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Foreword

A number of long-range forecasts of international demographic and economic trends have been published over the last decade, many of them based on the findings of global models—computerized mathematical simulations of the world's physical, economic, and political systems. This report responds to a request by the Technology Assessment Board for an evaluation of the methodologies, findings, and implications of Global 2000 and other global modeling studies.

Computerized models are a useful way of handling a large amount of data at once and of keeping assumptions and calculations self-consistent. In this connection, our study not only reviewed the findings and recommendations of five major global modeling studies, but also examined the underlying assumptions and data bases on which those results are based.

The purpose of this report is neither to confirm nor to disprove the sometimes rosy but more often dire predictions derived from global modeling studies, but rather to examine the present use and potential usefulness of this rapidly developing technology as a powerful tool for long-range strategic analysis and policy development. OTA found significant and growing use of models by a variety of Federal agencies. In addressing the modeling capability of the Government, the report focuses not on whether models should be used—they already are, and have proven themselves valuable over a period of years—but rather on how to improve this capability and make its projections more useful to analysts, planners, decisionmakers, and the broader public.

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Overview

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CHAPTER 1

Overview

The last 15 years have witnessed a growing international effort to increase understanding and broaden public awareness of the conditions, problems, and opportunities that are likely to confront the world through the end of this century and into the more distant future. This ongoing "futures debate" has been stimulated in part by the publication of a series of long-range forecasts of global trends in population growth, resource availability, economic development, and environmental conditions. Many of these forecasts have been based on the findings of "global models' '—computerized mathematical simulations of the world's physical, economic, and political systems. As tools of strategic analysis, these models have been used to study the interactions and future implications of past events and current trends, As tools of policy formulation, global models have been used to evaluate or promote alternative actions and programs that might bring about different or more favorable world futures.

This report surveys the assumptions, findings, and recommendations of five major global modeling studies (see table 1). It also considers the use of global models within the U.S. Government, such as the World Integrated Model (WIM) that is being used by the U.S. Joint Chiefs of Staff (see pp. 23-24), In addition, the report presents strategies that have been suggested for improving the quality and relevance of the Government's modeling capability. Of great interest in this connection is the newly created White House "national indicators system" (see p. 65). The appendixes provide detailed comparative analyses of the models' projections of population, agriculture, and energy trends.

Table 1 .—Summary Description of the Five Global Modeling Studies Discussed in This Report

Model	Date	Historical base period	Projection time horizon	Geographical regions	Alternative scenarios[a]
World 3	1972	1900-1970	**2100**	1 (global)	11
World Integrated Model (WI M)	1974	1950-1975	2025	10 (later 14)	17
Latin American World Model (LAWM)	1976	1960-1970	2060	4 (later 15)	7
United Nations Input-Output World Model (UNIOWM)	1977	1970[b]	**2000**	**15 (3** blocs)	13
Global 2000	1980	Not consistent	**2000**	**5** to 28 (Not consistent)	12

[a]Number of computer runs, sensitivity tests, or policy scenarios examined by Office of Technology Assessment in the text of appendixes of this report
[b]System structure and behavior in 1970 were verified through comparison with cross-sectional data dating back to 1955 or 1960.

SOURCE: Office of Technology Assessment.

Findings of the Global Models

Global modeling studies have varied widely in their purposes, techniques, findings, and prescriptions. The results of some studies have been guardedly optimistic, while others have been highly pessimistic. Their specific quantitative results have been different because they have made different assumptions and have focused in different ways on different parts of the global system. Nevertheless, they have generally identified the same problems and seem to have arrived at roughly similar qualitative conclusions about the present state of the world and its plausible futures:

- Population and physical capital cannot grow indefinitely on a finite planet without eventually causing widespread hunger and resource scarcities. However, there is no physical or technical reason why basic human needs could not be supplied to all the world's people, now and for the foreseeable future. These needs are not now being met because of unequal distribution of resources and consumption—not overall physical scarcities. The absence of physical limits, however, does not necessarily imply the existence of a practical solution.

- The continuation of current trends would result in growing environmental, economic, and political difficulties. As a result, "business as usual" is not a palatable future course. Technological progress is expected (and in fact essential), but no set of purely technical changes tested in the models was sufficient in itself to bring about a completely satisfactory outcome. The models suggest that social, economic, and political changes will also be necessary.
- Over the next two or three decades, the world's socioeconomic system will be in a period of transition to a state that will be significantly different from the present. However, the shape of this future state is not predetermined—it is a function of decisions and changes being made now.
- Because of the complexity, momentum, and interdependency inherent in the world's physical and socioeconomic systems, the full long-term effects of a given action are almost impossible to predict with precision or certainty. However, actions taken soon are likely to be more effective and less costly than the same set of actions taken later, and cooperative long-term approaches are likely to be more beneficial for all parties than competitive short-term approaches.
- Many existing plans and agreements—particularly complex, long-term international development programs—are based on assumptions about the world that are either mutually inconsistent or inconsistent with physical reality.
- Pollution and resource availability may or may not be problems on a global 'scale," but there is general agreement that regional problems of global concern—such as food shortages in South Asia and perhaps Sub-Saharan Africa-are far more likely than a global collapse.

In some cases individual global models have been used to support more dramatic conclusions and more specific prescriptions than these, but it would be a mistake to confuse global modeling us a method of analysis with any particular prediction or recommendation. As a tool of analysis, global modeling is in itself neutral, although like any complex tool a given model can be designed or used inappropriately. For instance, most global models contain little or no representation of geopolitics; it would thus be inappropriate to use them to predict short-term events that may in fact be more strongly affected by nonquantifiable political variables. Similarly, the findings that come out of a model will also depend on the data and assumptions that go into it, the purposes to which it is put, and the way it is interpreted. As a result, global modeling can be a useful technique in long-range analysis, but it should not be—nor is it likely to become—the sole, or even the principal, basis for decisionmaking.

Global Modeling and Government Foresight

Global modeling is used by a variety of organizations and is by no means the exclusive preserve of environmentalists or those who advocate a "new international economic order. " A growing number of large domestic and multinational corporations routinel y employ the projections of private economic modeling services in their corporate planning. Several foreign governments and international organizations support ongoing global modeling programs, and a variety of models—global and otherwise–are also in use throughout the U.S. Government in a wide range of forecasting applications. The Joint Chiefs of Staff, for example, are developing a version of WIM for use in their joint long-range strategic appraisal, and both the Department of Agriculture and Bureau of

Mines have used WIM as well as other models. The Global 2000 Study found that numerous Federal agencies (including the Central Intelligence Agency and Department of Energy, as well as the Agency for International Development, Bureau of the Census, and Environmental Protection Agency) routinely use regional or sectoral models in carrying out their long-range analysis and planning functions. Similarly, the Members and committees of Congress have access to long-term econometric models maintained by the Congressional Budget Office (as well as the findings of models maintained by the executive agencies) for use in their oversight, assessment, and legislative functions. This Government modeling capability exists because it is necessary, and it has shown itself to be useful over the years.

The expanded and better coordinated use of global models could offer the U.S. Government an opportunity to improve its existing foresight capability. "Foresight" relates to the ability to effectively address long-range issues by first anticipating future developments, and then formulating policies and programs that will minimize potential problems or exploit potential opportunities. Although global models cannot generate precise, detailed predictions of what will happen in the future, they can be used to produce conditional forecasts of what is likely to happen or the probability of different outcomes, given certain specific assumptions about trends, policies, and events. They can also be used to test the consistency of assumptions and predicted outcomes for different policy options. In addition, the models can generate order-of-magnitude estimates of many demographic, economic, and resource factors at the global, regional, and national levels.

This level of forecast accuracy and detail can be useful for a wide range of applications in long-range assessment and policy-development activities. Deficiencies do exist in the Government's current capability, but if these deficiencies are corrected global models could become a more effective input to policymaking in four specific areas:

- assessing the future impacts of current trends and existing policies;
- monitoring the national and international situation to identify early signs of potential problems or opportunities;
- formulating and testing a wide range of alternative policies and courses of action for achieving national goals, avoiding potential problems, and exploiting potential opportunities; and
- providing a framework to ensure consistency between short- and long-term analyses and across agency jurisdictions.

Strengths and Weaknesses of Global Models

Global models offer a number of methodological advantages over traditional techniques of long-range analysis and policy development:

- Longer time horizon. -Traditional methods are used primarily for annual or short-term forecasts, whereas global models typically have horizons of 20 years or more. This allows global models to assess long-term effects and cumulative changes that might not otherwise be anticipated.
- Comprehensiveness. —The computer can contain far more information about a system or process than any single mental or verbal model, and it can keep track of far more interrelations and variables at the same time. Global models can therefore enable the analyst to utilize substantially more information, and do so more meaningfully (e.g., with regional disaggregation) than could otherwise be done.
- Rigor and accessibility. -Modeling requires explicit, precise, and complete statements of objectives, assumptions, and procedures. These must be written out before they can be run on the computer, and this makes it easier for all sides to examine them and point out omissions and inconsistencies. Open communication about the system and the model can lead to revisions and refinements even before analysis begins, and it can also contribute to the dialog through which clear-cut goals are established.

- Logic.—The computer can draw logically correct and mathematically error-free conclusions from an extremely complicated set of assumptions and data. This can lead to insights into unexpected or counterintuitive system behavior, reveal areas in which further research is needed, and expose assumptions and objectives that are inconsistent, contradictory, or physically impossible.
- Flexibility. -It is possible to tailor global models to fit particular problems or regions. By changing the magnitude of specific variables and relations, global models can also be used to test a wide range of assumptions and policy alternatives. This can make the global model a valuable tool for policy formulation, as well as a device with which planners and policy makers alike can sharpen their analytic skills and improve their intuitive "feel" for the probable behavior of global systems.

Global models are, however, subject to a number of limitations that can constrain their accuracy, reliability, and usefulness:

- Methodological constraints. -The essence of modeling is a simplification that improves understanding, but this means that a limited set of discrete factors and relations are used to describe the complexity and ambiguity of the real world. There is little agreement, however, on the proper level of complexity or integration. Similarly, there are no generally accepted tests of model realism, making quality control and third-party validation important considerations.
- Theoretical constraints.—Current understanding of some causal relationships is far from adequate, particularly for environmental and sociopolitical processes, and this too can lead to inaccurate or invalid assumptions. As a result, the theoretical biases of the modelers-or the specific needs and assumptions of model users—can sometimes lead to oversimplification or distortion.
- Data constraints.–In many areas there is a lack of adequate, reliable, and consistent data. This, too, can be a source of forecast error, as well as a constraint on the issues or regions to which global models can be reliably applied.

Because of these limitations, it is vital to evaluate the assumptions and uncertainties underlying the forecasts, if the results are to be understood and used by policy makers.

Institutional Barriers

Several assessments of the Government's modeling capability have concluded that the institutional context in which models are currently used is as much of a constraint on their usefulness as the above technical limitations. Frequently cited institutional barriers include the following:

- poor communication between modelers and potential model users, resulting in projections that are unresponsive to the information needs of policy makers;
- narrow specialization of interests and responsibilities, at the expense of interactions among sectors and cooperation among agencies, complicated by inadequate mechanisms for transferring data and resolving problems between agencies;
- lack of understanding, confidence, or support for modeling among top-level policy makers, resulting in a failure to integrate forecasting and policymaking activities; and
- lack of interest in long-term global issues on the part of the Federal agencies, Congress, and the general public.

Strengthening the Government's Modeling Capability

Proposals for improving the Government's modeling capabilities usually stress the need for a coordinated strategy involving complementary efforts at all levels. The proposed initiatives generally reflect four fundamental priorities:

- Correct existing deficiencies.—Relevant agencies might create internal advisory committees to: 1) prepare an inventory of existing models, their uses, their deficiencies, and any planned modifications; 2) conduct a survey of current or potential applications by analysts and policymakers, with particular attention to their specific information needs; 3) evaluate existing data bases to determine data needs and possible ways of gathering data that are scarce; and 4) improve communication between policymakers and modelers in order to increase the relevance and responsiveness of forecasts.
- Coordinate existing capabilities and activities.—Some form of interagency mechanism might be established in order to: 1) identify areas of compatibility and sources of inconsistency among models; 2) promote communication and technical cooperation among agencies; 3) develop consistent standards and protocols for the reliability, validation, and documentation of both models and data; 4) provide a clearinghouse for easier access, exchange, and integration of other agencies' data, assumptions, and projections; and 5) resolve problems among agencies through negotiation or arbitration.
- Support technical improvements in the Government's capability and the state of the art.—An independent or "quasi-public" institute might be created to promote research on global modeling and futures research. Its specific functions might be to: 1) encourage impartial, third-party validation and assessment of existing models; 2) support nongovernmental research on global models and establish a "global modeling forum" (analogous to the Energy Modeling Forum at Stanford University) at which modelers could exchange ideas and critique one another's work; 3) enlist the talents and participation of the private sector in Government foresight activities; and 4) assess modeling work done outside the United States and maintain communication with international organizations such as U.N. agencies and the International Institute of Applied Systems Analysis.
- Link foresight with Policymaking. -To ensure that long-range global issues are routinely taken into consideration in the formulation and implementation of U.S. policy, Congress may wish to coordinate and upgrade the foresight capabilities of its legislative research agencies and/or authorize the creation of a new unit in the Executive Office of the President. The functions of this new unit might be to: 1) supervise and/or coordinate the strategies outlined above; 2) provide the President and other top-level decisionmakers with thorough analyses and a broad range of policy options on global issues; 3) evaluate the long-term effects of agency goals and budget items on global trends and U.S. strategic interests, for consideration by the Office of Management and Budget and Congress in the budgetary process; 4) prepare a "policy statement on the future" to be delivered by the President; 5) issue periodic reports on specific global issues; 6) conduct comprehensive, integrated studies of long-range trends and problems at regular intervals; and 7) in conjunction with the Department of State, encourage foreign national assessments of long-range issues and support the data-gathering, analytic, and problem-solving activities of the United Nations, international financial institutions, and nongovernmental organizations.

Conclusions

1. Global modeling represents an important analytic tool for exploring alternative world futures and for testing the feasibility and long-term effects of alternative policy actions.
2. The current state of the art in global modeling offers the U.S. Government a significant opportunity to improve its foresight capability, if the models are used judiciously and in combination with other techniques and inputs to strategic analysis and policy development.
3. If models are to be used properly within their present limitations, it is critical to: 1) determine and state explicitly the purposes, assumptions, and theoretical biases of the model; 2) ascertain the extent of uncertainty in a particular projection and its sensitivity to changes in the underlying assumptions; and 3) differentiate between descriptive forecasts and those that are prescriptive or normative.
4. Improvements in socioeconomic theory, modeling methodology, and data-gathering technologies could substantially improve the usefulness of the projections generated by global models.
5. Existing deficiencies in the Government's modeling capability are institutional as well as technical in nature, and any effort to correct these deficiencies will require better coordination among Federal agencies and increased attention to the information needs of policymakers and decisionmakers.

CHAPTER 2

Major Global Modeling Studies

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Major Global Modeling Studies

Introduction

Forecasts and Forecasting

Formal forecasting, which appeared in the early 20th century, is based on the rigorous application of empirical inquiry and statistical analysis to the prediction of socioeconomic change. It insists on careful monitoring, a firm data base, and the judicious use of trend extrapolation, while rejecting unfounded optimism and utopianism as "wishful thinking." The first use of formal forecasting by the U.S. Government came in 1929, when President Hoover created a Presidential Research Committee on Social Trends, and its techniques and findings became linked with comprehensive planning and decisionmaking during the New Deal. Further theoretical improvements and practical applications have emerged since World War 11 through developments in econometrics, general systems theory, cybernetics, operations research, and input-output analysis.[1]

For strategic analysis and policymaking purposes, three general types of forecasts can be distinguished, based on their approach to foreseeing the future:[2]

- unconditional forecasts, which determine that certain events or trends will, in all probability, occur in the future (these forecasts might properly be called "predictions");
- conditional or probabilistic forecasts which determine that certain events or trends are more or less likely to occur in the future, given certain limiting assumptions concerning present and future conditions and policy actions (and that, given a different set of assumptions, different events or trends are more or less likely to occur); and
- exploratory forecasts, which examine a wider range of policies and trends in an open-ended exploration of possible future developments, with less emphasis on the plausibility of assumptions or scenarios.

To these three types of descriptive forecasts, which attempt to project what will or might happen in the future, a fourth could be added:

- prescriptive or normative forecasts, which identify events or trends that should (or should not) happen and determine the policies and conditions that will promote the desired outcome.

Models and Modeling

A model is a simplified or generalized representation of something else—an object, process, or system. The model need not resemble the original and can in fact take many forms, depending on the purpose it is to serve: as an aid to memory, a small two-dimensional photograph can remind us of a large three-dimensional person or place we have seen; as an aid to discocery, a 3-lb model airplane can be tested in a wind tunnel to predict the performance of a 30-ton airliner built on the same design; and as an aid to explanation, a set of gravitational equations can be used to elucidate the intricate motion of planets orbiting a sun.

The model need not depict every detail of the thing it represents. A good model reduces the complexity of the original by eliminating elements and relations that are irrelevant to the purpose at hand, retaining only the characteristics that are needed for that purpose. Ingeniously simple models may be described as "elegant, " but in the end "a model can be made and judged only with respect to a clear purpose."[3]

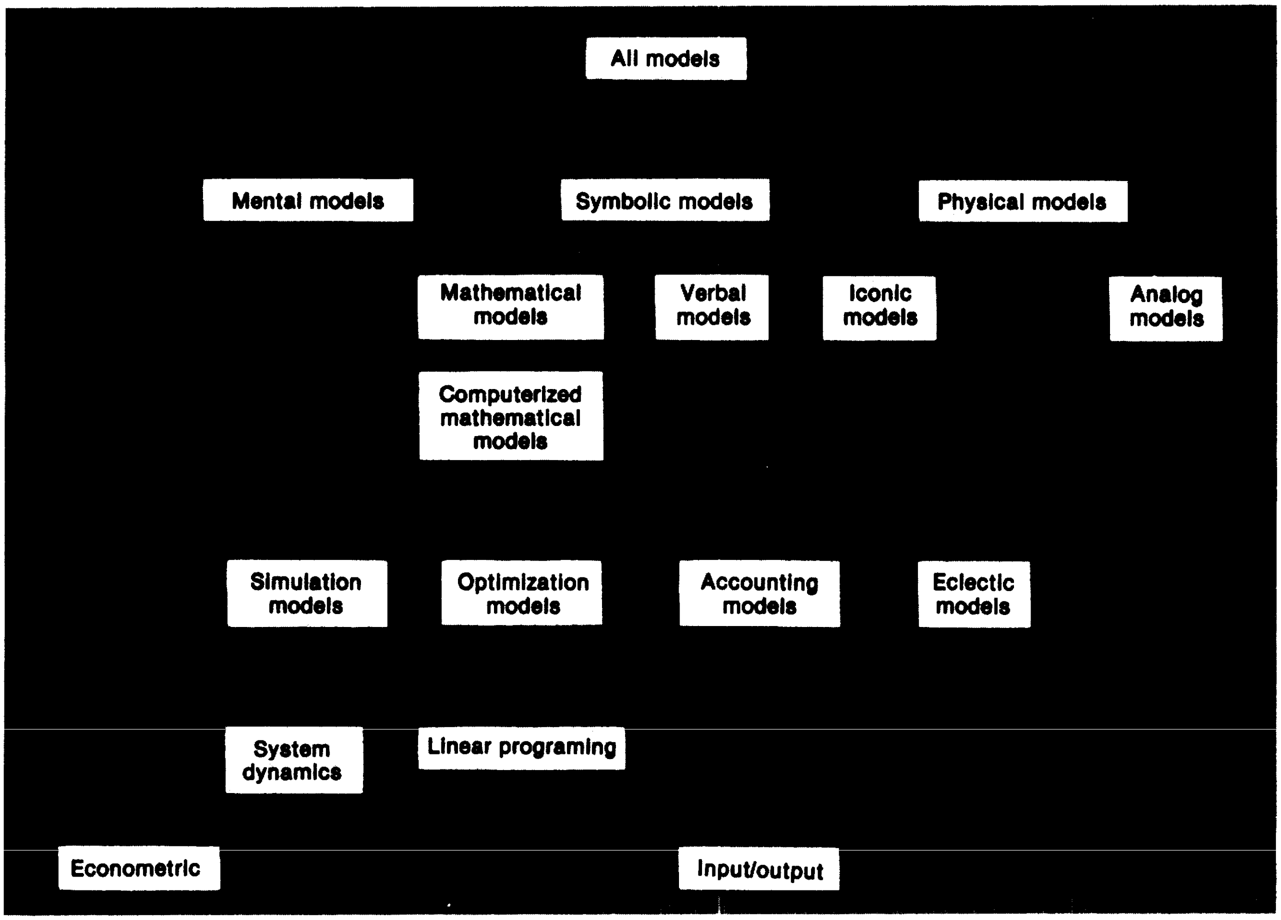
Models can be divided into three basic types: mental models, physical models, and symbolic models (see fig. 1). Mental models are the concep-

[1]Dennis L. Little, et al., *Long-Range Planning* (Washington, D.C.: U.S. Library of Congress Congressional Research Service, 1976), prepared for the Subcommittee on the Environment and the Atmosphere of the House Committee on Science and Technology, pp. 384-390.

[2]Arthur D. Little, Inc., *Long-Range Forecasting Models of Population, Natural Resources, and the Environment: Their Use in Foreign Policy Assessments at the National Level* (prepared for the U.S. Department of State, Nov. 1979), pp. II.2-3.

[3]Donella H, Meadows, John Richardson, and Gerhart Bruckmann (eds.), *Groping in the Dark The First Decade of Global Modeling* (New York Wiley, forthcoming), pp 37-38; emphasis theirs.

Figure I.—Types of Models



SOURCE: Arthur D. Little, Inc.

tual models people carry about in their heads and use to think about the world. They are flexible, adaptable, creative, and contain rich stores of information about such intangible factors as values and motivations. Some mental models are extremely subtle and elaborate, even elegant. But they can also be vague, shifting, unverbalized, and immune to objective criticism, and they are often based on dubious but strongly held assumptions. Judgmental and qualitative forecasts (including many unconditional forecasts) are often based on mental models.[4]

Physical models are created from tangible materials, and the process of embodying the model can usually make it both more explicit and more open to objective criticism. Iconic or schematic models, such as maps or diagrams, are physically similar to their originals, although they may not behave in the same manner. Analog models, such as wind tunnels, reproduce the behavior of their originals without necessarily resembling them in appearances Physical models can be a useful means of communicating, clarifying, and correcting mental models.

Symbolic models make use of some system or language of symbols to describe the relevant elements and relations of the object, process, or system they represent. Verbal models, such as Das Kapital or Wealth and Poverty, take the form of oral or written language. As a result, they can be more

[4]Ibid., pp. 20-21, 37-38; and Arthur D. Little, Inc., op. cit., p. II.6.

‘Arthur D. Lttle, Inc., op. ctt., p. 11.6.

explicit and precise than mental models, but at the same time they are potentially diffuse, impressionistic, ambiguous, and rhetoric al. Mathematical models, on the other hand, can represent the relevant elements and relations of a real object, process, or system in mathematical symbols and equations. This allows them to express complex operations concisely, precisely, and explicitly in a rigorous and consistent language. This in turn makes them more open to objective criticism and correction, but mathematical models remain susceptible to omissions, distortions, and misinterpretations like those that afflict mental and verbal models. They can be no more valid or reliable than the theoretical understanding on which they are based and the mathematical form in which they are expressed.

Computerized models are mathematical models that have been rewritten in a programing language that can be run on a computer. They can be used to investigate a process, system, or theory that is too large or too complicated to model adequately (or manipulate conveniently) in words or a few simple equations.[6] Such models can contain more elements (variables), more relations (equations), and far more empirical data than simpler models. The computer can keep track of all of these factors simultaneously, manipulate them very rapidly, and produce results that are free from computational error. However, human judgment is still required to determine what factors to include, hem' to represent them, what data to use, and how to interpret the numerical findings. Consequently, the results that come out of the computer are only as reliable as the general assumptions, structural decisions, and data that go into it, and even the best results are subject to biased or mistaken interpretations.

Global models are simply computerized mathematical models whose purpose is to investigate systems, theories, and issues of a global scale and complexity, usually with a relatively long time horizon:

> Global modeling is distinguishable from other types of modeling of social systems only by the questions it asks. Its methods, strengths, and weaknesses are identical to those of all policy-oriented computer models. It draws from the same base of theory and data. Therefore, if there are any distinct properties of global modeling, they follow directly from the characteristics of global problems.[7]

The following survey will therefore focus not only on the modeling techniques that have been used and the findings that have resulted, but also on the global problems that have been addressed in the models and the purposes to which their findings have been put.

[6] Meadows, Richardson, and Bruckmann, op. cit., p. 20.

[7] Ibid., p. 45.

The Trend Away From Technological Optimism

Until about 1970, most long-range forecasts were characterized by generalized optimism about the benefits of continued economic growth and confidence in the ability of technology to overcome any barriers. The most influential of the forecasts was The Year 2000, by Herman Kahn and Anthony Wiener of the Hudson Institute, which offered a set of alternative "scenarios" as a "framework for speculation" on the future. Its central finding was "that economic trends will proceed more or less smoothly through the next thirty years and beyond," and that "we are entering a period of general political and economic stability at least so far as the frontiers and economies of most of the old nations are concerned."[8] This "surprise-free" scenario was based on exponential extrapolations of postwar demographic and economic trends, but it was also influenced by the authors' underlying assumption of "continuity" in global affairs, particularly the increased rate of technological innovation, and by their confidence that society would be able to find "physically non-harmful methods of over-indulging."[9] Kahn and

[8] Herman Kahn and Anthony Wiener, *The Year 2000: A Framework for Speculation on the Next Thirty-three Years* (New York: Morrow, 1967), pp. 116-128; emphasis added.

[9] Ibid., pp. 6, 122, 52.

Wiener do caution that "increasing discrepancies between rich and poor" could lead to resentment and instability, and that the "problems of development constitute a serious economic and moral concern."[10] Nevertheless, according to one critic, "they simply refuse to be overawed by the magnitude of the problems posed."[11] Although sharply criticized in recent years, this view of the future has remained influential in both Government and corporate policy, as well as public opinion, in the United States.[12]

Since the late 1960's–and particularly since the 1973 oil embargo–a less optimistic view of the future has gained currency, a view characterized by increased concern for the feasibility and environmental consequences of unrestrained economic growth and by criticism of the social and political institutions that have supported such growth, This new mood, which has been characterized as "neo-Malthusian pessimism," was influenced in part by the projections of economist Joseph Spengler and by the popular success of several books by Anne and Paul Ehrlich, who argued that the world is already over-populated and overdeveloped in terms of its ecological resources.[13] By far the largest stimulus to public debate over these issues came from the activities of the Club of Rome (an international group of businessmen, academics, and civil servants) that was organized in 1968 by Italian management consultant Aurelio Peccei,

The Club of Rome's "Project on the Predicament of Mankind" focuses on the complex interacting socioeconomic problems that make up the so-called "world problematique:"[14]

- poverty in the midst of plenty;
- degradation of the environment;
- loss of faith in institutions;
- unconrtolled urban spread;
- insecurity of employment;
- alienation of youth;
- rejection of traditional values; and
- inflation and other monetary and economic disruptions.

The predicament of mankind, according to the Club, is to be able to perceive this problematique but to be unable to understand its origins or operation and, therefore, unable to respond to it effectivelv.

The Club's continuing program, consequently, has two objectives: 1) to gain a better understanding of the limits of the world system, the interaction of its dominant elements, and the constraints it puts on human numbers and activities;[15] and 2) to encourage appropriate sociopolitical reforms by bringing the world problematique to the attention of the general public and (more pointedly) the world's leaders and decisionmakers. The Club "hit on the idea of using a computer to advertise their cause," as one critic puts it, not only because "the field of Systems Dynamics had created a body of expertise uniquely suited to the research demands," but also because the resulting report might prove to be "a vehicle to move the hearts and minds of men out of their ingrained habits."[16] These dual purposes led to the first true global model, which also remains the best known and the most controversial.

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[10] Ibid., pp. 142, 364.

[11] Sam Cole, "The Global Futures Debate 1965-1976," in *World Futures: The Great Debate*, Christopher Freeman and Marie Jahoda (eds.) (New York: Universe Books, 1978), p. 23.

[12] M. Marien, "Herman Kahn's 'Things to Come,'" *Futurist*, February 1973, p. 7; cited by Cole, op. cit., p. 23.

[13] Cole, op. cit., p. 27; see also Joseph Spengler, "The Economist and the Population Question," *American Economic Review*, December 1966, and *Population Change, Modernization and Welfare* (Englewood Cliffs, N.J.: Prentice-Hall, 1974); see also Paul R. Ehrlich, *The Population Bomb* (New York: Ballantine Books, 1968), and Anne and Paul R. Ehrlich, *Population, Resources, Environment: Issues in Human Ecology* (San Francisco: Freeman, 1970).

[14] William Watts (President, Potomac Associates), "Foreward," in *The Limits to Growth*, by Dennis L. Meadows, et al. (New York: Universe Books, 1972), pp. 10-11.

[15] Aurelio Peccei, et al., "Commentary," in *The Limits to Growth*, p. 185.

[16] Cole, op. cit., pp. 28-29; and Watts, op. cit., p. 11.

World 3—The Limits to Growth

Origin and Purpose

In June 1970, when the Club of Rome was seeking a suitable methodology for their investimation of the global system, Jay For-rester of the Massachusetts Institute of Technology (MIT) invited the group to Cambridge for a demonstration of the capabilities of systems dynamics. Within 3 weeks he designed and documented a simple global model - World l - as the basis for presentations and discussions at the end of July 1970. (A revised version, World 2, was the subject of Forrester's subsequent World Dynamics (197l).) Impressed, the Club obtained a $250,000 grant from the Volkswagen Foundation to fund For-rester's colleague Dennis Meadow's and a team from MIT in developing a full-scale model—World 3—based on the systems dynamics approach. Under the auspices and direction of the Club of Rome, the MIT team produced both an elaborated model and a popularized presentation of it in less than 2 years—perhaps too quickly, in the view of one critic:

> The Club only relinquished control then the exercise had produced their desired product, as evidenced by the fact that client pressure drove the modelers to violate their scientific values by publishing The Limits of Growth beforc the technical documentation for World 3 was completed.

Structure and Assumptions

The World 3 model describes the global system in terms of five interacting subsystems—population, natural resources, capital, agriculture, and pollution-which are averaged on a global basis. Its most important conceptual contribution is the incorporation of "feedback" relations between these variables; due to these relations, attempts to solve one problem may unintentionally exacerbate another. The model also introduced the concept of "carry-- ing capacity "—the level of population and production that could be sustained indefinitely by the prevailing physical, political, and biological systems of the world-and posited four possible "behavior modes" that a growing population could exhibit with regard to this carrying capacity (see fig. 2). None of these behavior modes reflects the potential ability of technology to expand the carrying capacity, primarily because the model assumes nonsubstitutibility between technology and resources.

The purposes of the model, according to the authors, were "to determine which of [these] behavior modes . . . is most characteristic of the globe's population and material outputs under different conditions and to identify the future policies that may lead to a stable rather than an unstable behavior mode,"[18] According to one critic, however, given the authors' "specific motivating concern with limits, the broad conclusions that emerged from the model are, perhaps, not surprising"—they assumed that limits exist and would eventually be reached; "[the] question was when and how."[19]

Findings of World 3

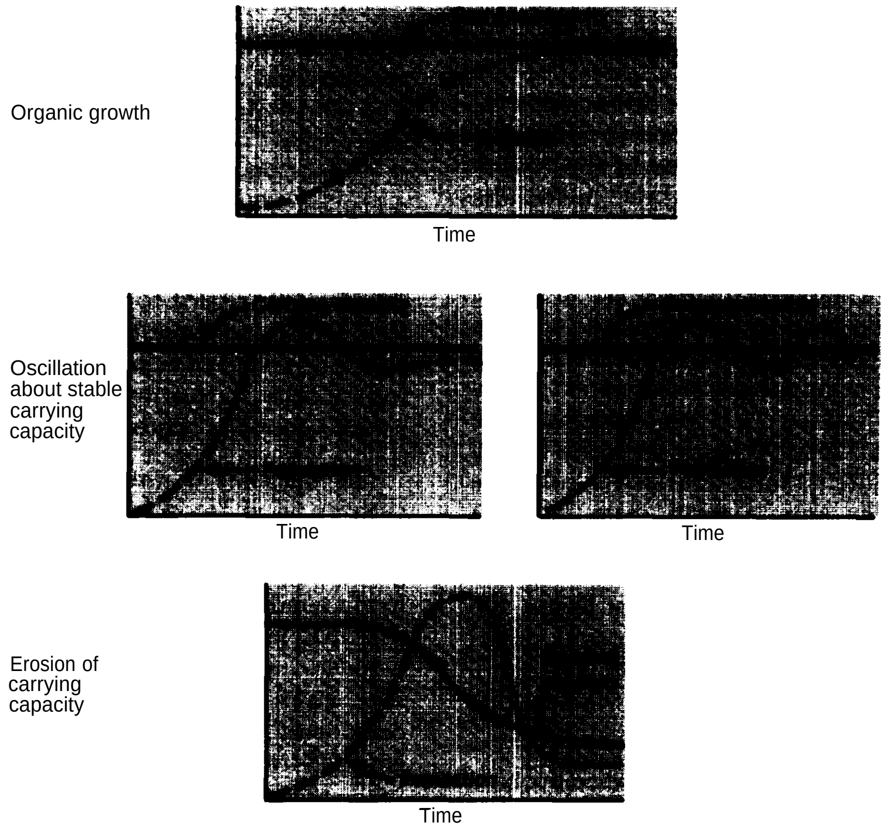
The standard or "reference run" of World 3, based on a continuation of the trends that have characterized the world system since 1900, results in the model output that has given The Limits of Growth its reputation for "gloom and doom" (see fig. 3). In this case the collapse of the system is caused by rapidly expanding population and in-

[1] Jennifer Robinson in Meadows, Richardson, and Bruckmann, op. cit., p. 408

[18] Dennis L. Meadows, et al., *Dynamics of Growth in a Finite World* (Cambridge, Mass.: Wright-Allen, 1974), p. 8

[19] Meadows, Richardson, and Bruckmann, op. cit., p. 61

Figure 2.— Possible Global Behavior Modes



SOURCE: *Limits to Growth.*

dustrial output and a diminishing resource base. Essentially the same results are achieved in additional runs with increasingly optimistic assumptions about the five system variables:

- doubling the nonrenewable resource base;
- "unlimited" nuclear power and extensive recycling;
- strict and effective pollution control;
- doubling the average agricultural yield; and
- "perfectly effective" but voluntary birth control.

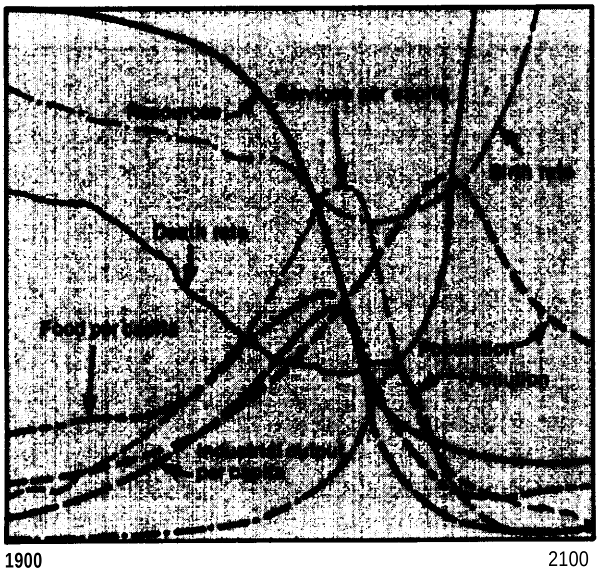
In some of the runs population and industrial production climb to higher levels before collapsing, but–according to this analysis–no single technological change can avert the final catastrophe, nor can any combination of them delay the collapse beyond the year 2100. In some runs the collapse is caused by a resource crisis, in others by a pollution crisis or a food crisis; but no matter what the assumptions, say the authors, "The basic behavior mode of the world system is exponential growth of population and capital, followed by collapse."[20]

In keeping with their second objective, the MIT team also used the World 3 model to identify conditions and policies that would avoid these problems and lead to a stable behavior mode like one of those in figure 2. Continuous growth was ruled out by the basic assumptions of the model; they were looking for an output that represented a "sustainable" world system that would avoid collapse and would also be "capable of satisfying the basic material requirements of all of its people."[21]

By working backward from the desired outcome to the conditions that would produce it, the authors were able to find a combination of "realistic" policy changes that, implemented simultaneously

[20]Meadows, et al., *The Limits to Growth*, p. 142.
[21]Ibid., p. 158.

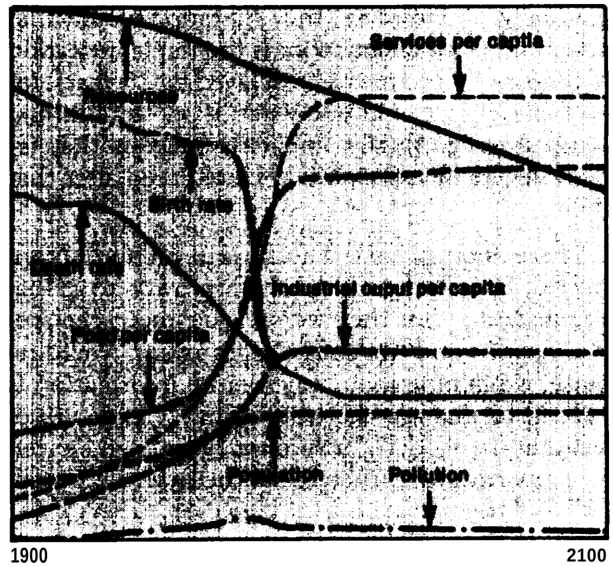
Figure 3.—World 3 Standard Run



The "standard" **world model run assumes no major change in the physical, economic, or social relationships that have historically governed the development of the world system. All variables plotted here follow historical values from 1900 to 1970. Food, industrial output, and population grow exponentially until the rapidly diminishing resource base forces a slowdown in industrial growth. Because of natural delays in the system, both population and pollution continue to increase for some time after the peak of industrialization. Population growth is finally halted by a rise in the death rate due to decreased food and medical services.**

SOURCE: Limits to Growth.

Figure 4.—World 3 Equilibrium Run



Technological policies and growth-regulating policies produce an equilibrium state sustainable far into the future. Technological policies include resource recycling, pollution control devices, increased lifetime of all forms of capital, and methods to restore eroded and infertile soil. Value changes include increased emphasis on food and services rather than on industrial production. Births are set equal to deaths and industrial capital investment equal to capital depreciation. Equilibrium value of industrial output per capita is three times the 1970 world average.

SOURCE: *Limits to Growth,*

in 1975, would lead to an "equilibrium state" (see fig. 4):[22]

- restrict population growth by reducing average desired family size to two children and making "perfect" birth control universally accessible (population stabilizes at about 6 billion in 2050, after a delay inherent in the age structure of the current population);
- restrict capital growth by maintaining average industrial output per capita at the 1975 level and holding the capital investment rate equal to the depreciation rate (excess capacity is used to produce consumer goods and services);
- reduce resource consumption and pollution generation per unit 'of industrial and agricultural output to one-fourth of their 1970 levels (largely through recycling and advanced abatement technologies);
- divert capital to agricultural production in order to produce sufficient food for all people, even if such an investment would be considered "uneconomic;"
- prevent soil depletion and erosion by using some of the agricultural capital for enrichment and preservation (e.g., comporting urban organic wastes and returning them to the land); and
- extend the average lifetime of industrial capital stock through improved durability and maintenance, in order to reduce obsolescence and make more capital and resources available for other sectors.

The authors recognized that different combinations of the above policies might be adopted by different societies, and that "[a] society choosing sta-

[22]Ibid., pp. 160-166.

bility as a goal certainly must approach that goal gradually."[23] However, they hastened to add that action must be taken soon: if the implementation of these policies were to be delayed by 25 years, for example, they would not result in an "equilibrium state" (see fig. 5); this implicitly suggests that far more severe measures would be required after that time.

These findings led the authors to call for a "controlled, orderly transition from growth to global equilibrium," but they were vague about the specific actions and tradeoffs this transition would require, explaining that "much more information is needed to manage the transition."[24] Some critics feel that the model's "no growth" bias "can be seen as supporting the interests of the materially well-off" and the rich nations.[25] However, others Point out that the equilibrium state necessarily implies a "world-wide radical egalitarian levelling of incomes and property,"[26] yet the MIT team has "almost nothing to say about what should or might happen to poor nations . . . under the policy of no growth."[27] Because of "their deliberate self-restriction to physical properties of the world," according to another critic, "they have chosen to be unconcerned with politics [and] social structure;"[28] The Limits to Growth speaks instead of the greater demands that will be placed on "humanity's moral resources."[29] Above all, however, the model's simplification and global aggregation of imperfectly understood factors make it unsuited for generating specific, detailed policy recommendations. This is a limitation shared by other global models:

> The breadth of focus and coherent conceptual development of the world models ensure their utility for clarifying the nature of long-term global problems. However, their limitations render them unsuitable as primary tools of analysis or as tools for detailed analysis of global problems and their solutions. 30

[23]Ibid., p. 167.

[24]Ibid., p. 180.

[25]Keith L. R. Pavitt, "Malthus and Other Economists: Some Doomsdays Revisited," in *Models of Doom: A Critique of the Limits to Growth*, H. S. D. Cole (eel.) (New York: Universe Books, 1973), pp. 154-157.

[26]Harvey Simmons, "Systems Dynamics and Technocracy)" in *Models of Doom*, pp. 206-207.

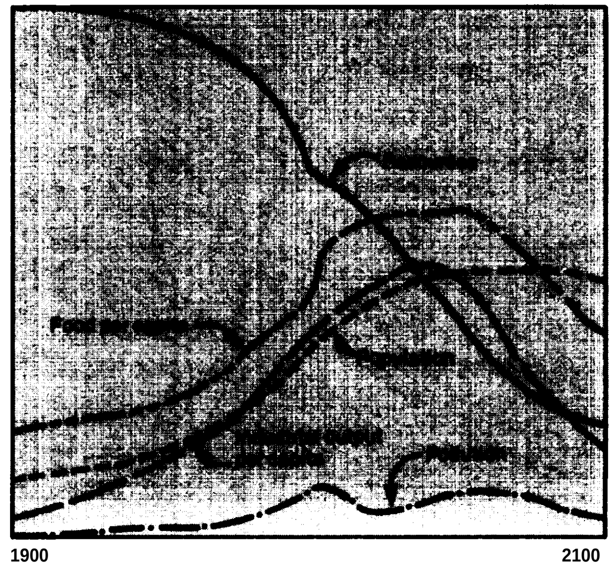
[27]Cole in *World Futures The Great Debate*, p. 29.

[28]Marie Jahoda, "Postscript on Social Change," in *Models of Doom*, p. 212.

[29]Meadows, et al., The *Limits to Growth*, p. 179.

[30]Jennifer Robinson, "worlds 2 and 3," in The *Global 2000 Report to the President* (Washington, D. C.: U.S. Council on Environmental Quality and Department of State, 1980), vol. 2, p. 608.

Figure 5.—World 3 Run With Stabilizing Policies Introduced in the Year 2000



If all the policies instituted in 1975 in the previous figure are delayed until the year 2000, the equilibrium state is no longer sustainable. Population and industrial capital reach levels high enough to create food and resource shortages before the year 2100.

SOURCE: Limits to Growth,

Conclusions of World 3

Within these limits, World 3 arrives at three central conclusions that have been influential in the subsequent "futures debate:"[31]

1. If present growth trends in global population, industrialization, resource depletion, pollution, and food production are allowed to continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years, resulting in a catastrophic decline in both population and industrial capacity.
2. These growth trends can be altered in such a way as to establish economic stability at levels that are both sustainable into the foreseeable future and capable of satisfying the basic material needs of all the world's people.
3. If the people and nations of the world decide to strive for this equilibrium state, the sooner they start working to attain it, the greater their chances for success will be.

[31]Meadows, Richardson, and Bruckmann, op. cit., pp. 67-68.

Similarly, the technical limitations that restrict the utility of World 3 have proven to be a stimulus for subsequent global models, whose purposes increasingly have been to achieve both greater specificity and greater relevance to the needs of policy makers.

World Integrated Model—Mankind at the Turning Point

Origin and Purpose

The World 3 model achieved most of the objectives set for it by the MIT team and by the Club of Rome, but system dynamics was still viewed with skepticism in traditional scientific and policy circles. As a result, the popularized report on the model, The Limits to Growth, **was** the subject of considerable debate and controversy because of its methods—primarily its radical aggregation of global factors—and because of its vagueness on policy issues. When the club began planning a followup in 1972, therefore, it sought a modeling approach that would accomplish three goals:[32]

- to represent the world as a system of interdependent regions, rather than a single homogeneous unit, and to represent those regions in greater sectoral detail;
- to develop recommendations that would be of more direct relevance to policy makers; and
- to gain greater acceptance from the scientific community by incorporating more "hard data" and, wherever possible, by explicitly employing state-of-the-art theories and methodologies from the relevant academic disciplines.

The model the club chose to support, again with funds from the Volkswagen Foundation, was the World Integrated Model (WIM). This model was developed in parallel by two teams, one led by Mihajlo Mesarovic at Case Western Reserve University in Cleveland and the other by Eduard Pestel (a member of the executive committee of the Club of Rome) at the Technical University in Hannover, West Germany.

The authors first presented their model at a conference for high-level policy makers sponsored by the Woodrow Wilson International Center for Scholars in Washington, D. C., then at the first global modeling conference of the International Institute for Applied Systems Analysis (IIASA) in Austria, and finally at a series of scientific meetings and congresses throughout the world. Only after these formal presentations—and the distribution of technical documentation to selected experts—did they release the popular description of the model in the fall of 1974.

[32]Ibid., pp. 72-74.

Structure and Assumptions

The WIM methodology is based on Mesarovic's "multilevel hierarchical systems theory," which views the world in terms of five interrelated planes or strata:

- the environmental stratum, which combines geophysical and ecological factors and corresponds roughly to the natural "carrying capacity," although perhaps too superficially to satisfy some environmentalists;
- the technology stratum, which embraces activities whose biological, chemical, or physical terms involve mass and energy transfer;
- the demographic-economic stratum, which combines the human population and industrial capital of World 3 and, with the environment stratum, makes up most of the model's content;
- the group stratum, made up of sociopolitical institutions, policies, and decisions, which are usually represented as sets of alternative scenarios among which the model user chooses; and
- the individual stratum, reflecting personal attitudes and values, again represented by alternative scenarios to be selected by the model user.

According to the theory, these levels ordinarily operate with a fair degree of independence, although they can become highly interactive under "crisis" conditions. The authors therefore feel that their model can help us to understand and predict the system's behavior in both present and future crises.[33]

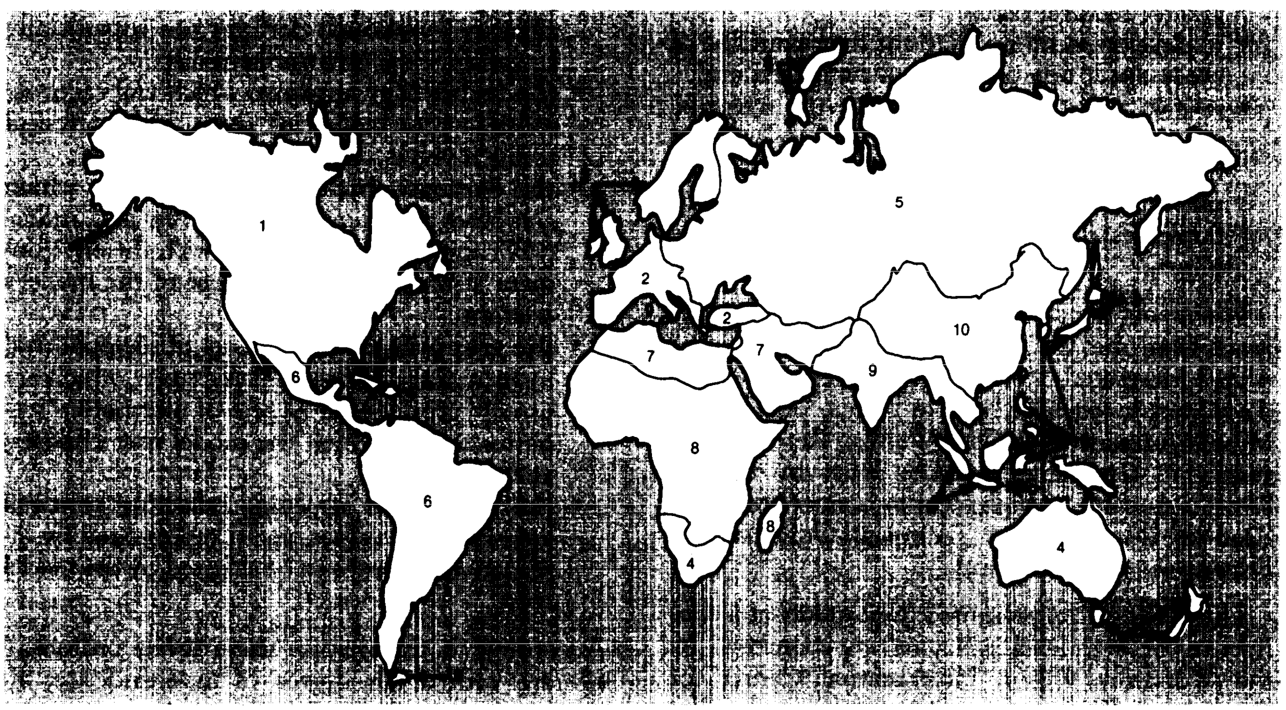
The major improvement in the WIM representation of the world system, however, is its greater geographic and economic detail (regionalization and disaggregation). Instead of a single homogeneous world, the model contains 10 regions made up of similar countries (see fig. 6), although in some runs they are grouped in three or four blocs. As a result, WIM can represent varying levels of development and resource endowment, as well as cultural and environmental differences; and it can therefore be used to investigate potential regional (as opposed to global) problems and crises. In addition, because these regions are connected by a trade network, WIM can be used to investigate the potentially mitigating effects of international trade (see fig. 7). Within each region, physical and economic sectors are differentiated into numerous subcategories—85 age groups for population, 19 categories for industrial capital, five for energy capital, two for agricultural capital, and so on. From the point of view of an economist, in fact, WIM is a collection of regional economic models. The resulting mathematical model is quite large: World 1 contained only 40 equations, and World 3 about 200, while WIM (according to its creators) contains over 100,000.[34]

Another improvement, one that is more directly relevant to policy applications, is the model's interactive design. The model user is allowed to estimate social and political behavior by selecting among alternative scenarios in the individual and group strata, thereby manipulating certain variables in such a way as to test a wide range of policy assumptions about energy prices, food exports, capital investments, and development aid. In addition, WIM's various submodels can be used independently to generate and test alternative policies for specific countries and regions. This capability

[33] Jennifer Robinson, "Mesarovic-Pestel World Model," in The Global 2000 *Report to the President*, vol. 2, p. 616.

[34] Cole in *World Futures:* The Great Debate, p. 34

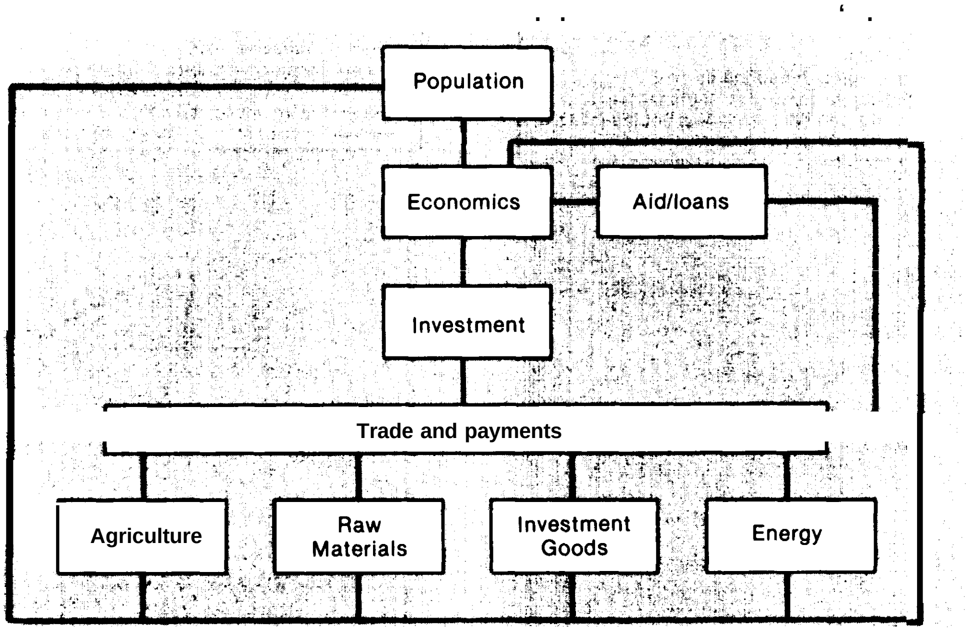
Figure 6.—Regionalization of the World integrated Model



NOTE: Later versions of World Integrated Model divide regions 1, 5, 6, and 7 into two regions each, for a total of 14 regions; they also have the capability of subdividing these new regions into five subregions each, depending on the level of detail required.

SOURCE: Mankind at the Turning Point.

Figure 7.—Block Diagram of the Basic Elements of the World Integrated Model



SOURCE: Command and Control Technical Center.

was in fact one of the stated objectives of the modelers:

> We hoped thus to furnish political and economic decisionmakers in various parts of the world with a comprehensive global planning tool, which could help them to act in anticipation of the crises at our doorstep and of those that loom increasingly large in the distance, instead of reacting in the spirit of short-term pragmatism.[35]

In keeping with this objective, which is shared by the Club of Rome, the WIM team at Case Western Reserve has actively marketed their model, using satellite-telephone patches to make presentations to prime ministers and other officials in at least 18 different nations.

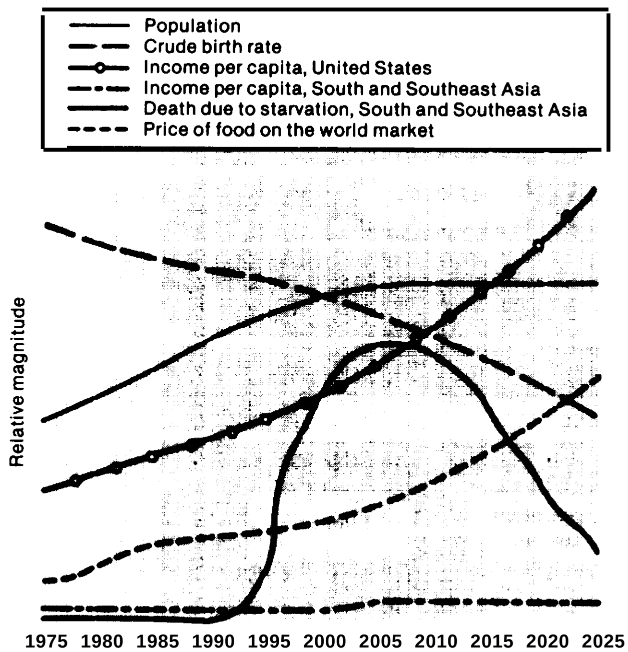
Findings of WIM

The WIM model has shown its versatility in extensive use for policy testing, both to evaluate alternative scenarios within its own assumptions and to test the scenarios and assumptions of other modelers and futurists.[36] Because the purpose and output of the model vary significantly from user to user and run to run, however, it is difficult to isolate any particular "results," although several test runs are illustrative. The reference or "historical scenario" run of the model, based on a continuation of present trends, results in the model output shown in figure 8: a steady increase in the real cost of food on the world market, which would also drive up domestic prices in the United States, and a catastrophic increase in the number of deaths caused by starvation in South Asia. The alternative "isolationist scenario" (fig. 9) indicates that, should the United States act to keep domestic food prices down by restricting exports, starvation in South Asia comes sooner and is even more widespread. In another pair of policy tests (fig. 10), the model output suggests that a policy of low, fixed oil prices leads to a catastrophic economic decline in the developed world when the resource is exhausted, whereas "optimal" price increases (per-

[35]Mihajlo D. Mesarovic and Eduard Pestel, *Mankind at the Turning Point* (New York: Dutton, 1974), p. ix.

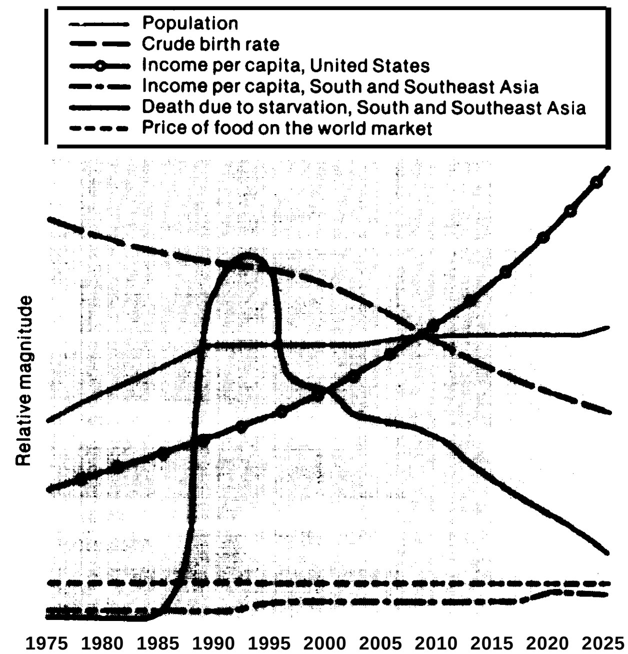
[36]See for example Barry B. Hughes and Mihajlo D. Mesarovic, "Testing the Hudson Institute Scenarios" (Washington, D. C.: U.S. Association for the Club of Rome, Sept. 1979), mimeograph.

Figure 8.—WIM Historical Scenario



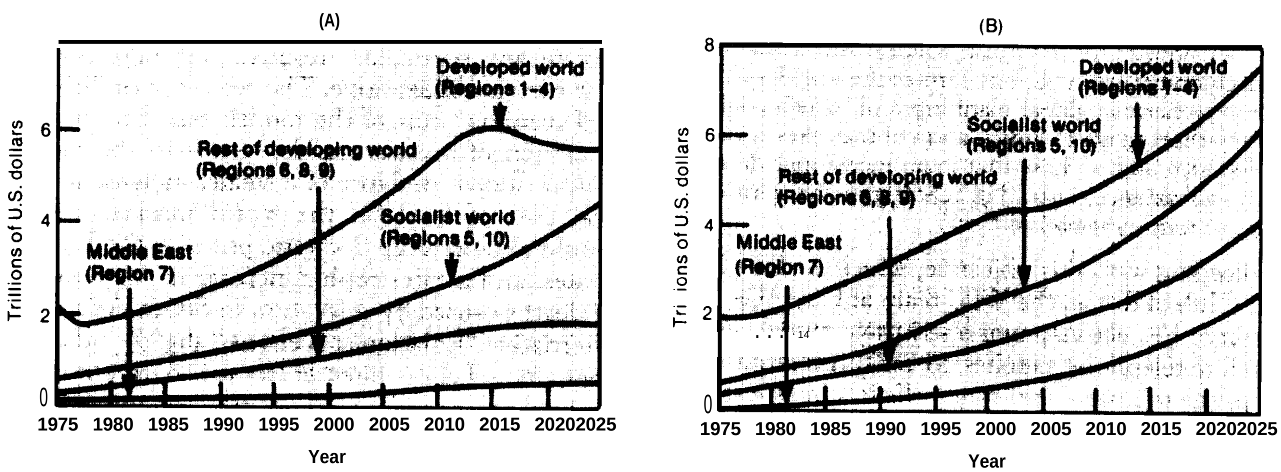
SOURCE: Systems Research Center, Case Western Reserve University.

Figure 9.—WIM Isolationist Scenario



SOURCE: Systems Research Center, Case Western Reserve University,

Figure 10.–Comparison of WIM Low" and Optimal"Price Oil Scenarios



Cheap energy in the form of oil has been a prime fuel for the unprecedented growth of the world economy in the 1950's and 1960's. The dramatic increase in oil prices in 1973 was viewed as a catastrophe. However, computer analysis of our world system model indicates that the continuation of what amounts to overexploitation of oil, spurred by an unreasonably low price, would lead to major dislocations because of the exhaustion of reserves and the lack of motivation to develop substitutes in time. Pursuance of short term objectives would lead to major dislocations in **the** long run (see A). A much **more beneficial development for all concerned results from the "optimal price scenario" in which the price is gradually increased up to the "optimum" level. Such a policy would bring in the substitutes in a more regular fashion while prolonging the reserves. Both exporting and importing regions would fare better (see B). It is only by taking a global and long term view that such a course of development, most beneficial to all concerned, can be identified.**

SOURCE: *Mankind at the Turning Point.*

mitting gradual adaptation and substitution) benefits both oil producers and consumers; a third oil-price scenario (not shown) suggests that increases above the "optimal" level leave all regions worse off.[37]

Conclusions of WIM

From these and numerous additional interactions with the model, the authors arrive at several conclusions about the nature of the world system and the management of future development:[38]

- the current crises in agriculture, energy, etc., are not transient but persistent, and represent the first signs of an "oncoming era of scarcity ;"
- the solutions to these crises cannot be found through isolated, short-term, or narrowly nationalistic strategies, but only through an integrated global context and "in the spirit of truly global" cooperation . . . guided by a rational master plan for long-term organic growth;" and
- "the time that can be wasted before developing such a global world system is running out ."

The model indicates that oil, substitutes for oil, and agricultural land will be the greatest constraints on growth. To address these problems, the authors recommend a policy of "organic growth," based on a recognition that the world system is a "collect ion of functionally interdependent parts, "[39] This policy, which would encourage growth where needed and discourage it where it "threatens not only that part but the whole as well, " include such specific steps as the following:[40]

- encourage worldwide diversification of industry to achieve a truly global economic system;
- build up the economic base and especially the export potential of the poorest countries so they can pay for food imports;
- give food aid to the poorest countries, but give investment aid only in the form of "intermediate" or appropriate technology; and
- carry out effective social and institutional reforms, because the required economic transfers are impossible under prevailing international economic arrangements.

The authors suggest that unless such steps are taken, spreading regional collapse and international tension will, like falling dominoes, eventually reach the developed world. If these and other steps are taken, on the other hand, "the world growth rates implied by (WIM's) computer results are much closer to those of Kahn and Wiener than to those of Meadows and Forrester. "[41]

U.S. Government Use of WIM

More recently, former members of the modeling team have designed a specially tailored version of WIM for the U.S. Department of Defense.[42] The model, which is fully operational, is maintained and operated by the Command and Control Technical Center (CCTC) in support of the Plans and Policy Directorate (J-5) of the Joint Chiefs of Staff. J-5 is currently creating a new division, specifically devoted to long-range analysis, which will use the model to develop projections of global systems behavior for use in long-range national security planning. At present, the model is being developed to provide data on political, economic, and demographic conditions under various subcontingencies of four basic scenarios or "future worlds" defined by J-5:

- "A-muted bipolarity," essentially a reference run based on current trends and international relations;
- "B-superpower dominance (conflict mode)," including contingencies representing different levels of East-West conflict;
- "C-superpower dominance (cooperation mode);" and
- "D-devolution of power," representing a future in which the superpowers must share world power with other groups of nations, and including contingencies for potential North-South conflicts, such as an oil embargo.

[37] Meadows, Richardson, and Bruckmann, op. cit., p. 83
[38] Mesarovic and Pestel, op. cit, pp. 85, 157.
[39] Ibid., pp. 5, 66.
[40] Cole in *World Futures: The Great Debate*, pp. 35-36.

[41] Ibid., p. 36.
[42] Material in this and the following paragraph is based on interviews with Col. Wilbert Jenkins, J-5, and Maj. Gary Knutson, CCTC; see also *World Integrated Model Multilevel Hierarchical Theoretic Concepts*, CCTC Technical Memorandum TM 197-79 (Washington, D.C.: U.S. Defense Communications Agency, June 15, 1979).

These WIM projections will become an input to the Joint Long-Range Strategic Appraisal beginning with its 1982 revision. CCTC also plans a complete update of its data base (facilitated by a new software package) and further refinements in WIM itself that may make it a more flexible tool for determining future military requirements. For instance, CCTC's version of WIM contains 12 geographical regions rather than 10 and will soon be expanded to 14, with the further capability of subdividing each new region into five subregions; it also contains 87 rather than 85 age groups and (for the United States and Soviet Union) a labor-skills submodel that further divides the population into male or female and urban or rural; and there have been similar refinements in the agricultural and materials submodels. These improvements create data problems, however, since reliable data are not available for many subregions and sectors. CCTC is working with the Bureau of Mines to update and expand the data base for the materials sector; in addition, J-5 has instructed CCTC to contact other Federal agencies about possible coordination of global modeling and strategic assessment activities. Such coordination might be facilitated in at least two cases by the fact that the Department of Agriculture, as well as the Bureau of Mines, is already using a version of WIM.

Latin American World Model—Catastrophe or New Society?

Origin and Purpose

When the Club of Rome presented the preliminary results of World 3 at a 1970 meeting in Rio de Janeiro, the reaction of the mostly Latin American audience was strongly negative. They felt that predictions of global crises, based on extrapolation of present trends and arrangements, reflected a parochial developed-world perspective; for two-thirds of the world's people such crises are already at hand. The audience refused to accept scenarios that implicitly curbed development and widened the income gap, and they felt that policies aimed at achieving a state of global equilibrium would merely ensure that the present disparities and inequities in the world system are perpetuated. They resolved, therefore, to design a model of an egalitarian "ideal society" in which basic human needs (not profits) would be the basis for resource allocation. The purpose of the model is to demonstrate the material viability of such a society, and thereby to demonstrate "that the different countries and regions of the world (particularly the poorest) could reach the goals we advocate in a reasonable period of time," relying primarily on their own human and economic resources.[43]

This global modeling effort was carried out at the Fundacion Bariloche in Argentina, with principal support from the International Development Research Center in Ottawa, and was first presented at the second IIASA modeling conference in Berlin in October 1974. An expanded version of the model, developed for the International Labor Organization (ILO), was warmly received at the 1976 World Employment Conference in Geneva, where "basic needs" were formally adopted as a major target of development.[44] The model continues to have considerable impact through United Nations organizations, including the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the United Nations Industrial Development Organization (UNIDO) as well as ILO, and it is by far the most popular global model among scientists and decisionmakers in the Third World.[45]

Unlike World 3 and WIM, which provide conditional descriptive forecasts of global trends, the Latin American World Model (LAWM) is openly and insistently normative—it is not concerned with "predicting what will occur if the contemporary tendencies of mankind continue, but rather with sketching a way of arriving at the final

[43] Amilcar O. Herrera, et al., *Catastrophe or New Society? A Latin American World Model* (Ottawa: International Development Research Center, 1976), p. 8.

[44] Cole in *World Futures: The Great Debate*, p. 39.

[45] Meadows, Richardson, and Bruckmann, op. at., p. 92.

goals of a world liberated from underdevelopment and misery. "[46] Its purpose is not to demonstrate that certain changes might bring the present world system into equilibrium, but rather "to show the feasibility of solving the fundamental problems through deep socio-political changes."[47] The model is also distinguished by its emphasis on the ideological issues involved in global modeling: the modeling team was composed of humanistic socialists,[48] and on questions of development and redistribution they "explicitly take up a stance favourable to the Third World in general, and to Latin America in particular."[49]

Structure and Assumptions

The LAWM team's goals and purposes lead them to include some rather unusual assumptions in the structure of their model. For instance, the model divides the world into four regions (later 15), each of which is treated as an economic unit, which "presupposes total collaboration between the countries forming it."[50] The model contains "simplistic" trade linkages: the contribution of international trade relative to regional gross national product (GNP) is held constant at the 1970 level, and all trade deficits are eliminated by 2000.[51] Instead, each region satisfied basic needs through "autarchy, " using almost exclusively local economic resources. However, these resources are assumed to be available in unlimited quantities and at constant cost: after a static analysis of current resource data, the modelers conclude that "the environment and its natural resources will not impose barriers of absolute physical limits on the attainment of [an ideal] society," at least not within a "historically significant time-scale. "[52] As a result, they do not include these physical factors in the computer model, and in this specific their model reflects a technological optimism akin to Herman Kahn's.

However, the authors do assume a radical change in the sociopolitical factors that control patterns of resource use—i.e., an equal distribution of consumption between regions and a total, egalitarian redistribution of income within regions. In addition, the model includes no assumptions about population policies, although it does include several untested assumptions about the effect of living conditions on demographic change. LAWM also appears to assume automatic growth in productivity through technological progress, at no cost, at rates between 0.5 and 1.5 percent annually depending on the sector.[53]

LAWM is essentially an economic model that operates through optimization procedures; i.e., it has five production sectors representing basic needs—food, housing, education, capital goods, and other goods and services—to which labor and capital are allocated through optimal control techniques in such a way as to maximize life expectancy at birth, which is taken to be the best indicator of general living conditions. These calculations proceed independently for each region from 1960 to 2060, but all countries are assumed to follow optimal policies after 1980.

Findings of LAWM

The standard or reference run of this optimization model indicates that all regions except Asia can reach their basic needs targets within 30 years. Developed nations (including the Communist world) "can reach high levels of well-being even if their economic growth rate is reduced drastically in the future" (fig. 11); in reality, economic growth is restricted to between 1 and 2 percent—far below the developed region's capacity for growth—which the authors acknowledge "assumes a political decision. "[54]

Latin America could fulfill basic needs by the early 1990's by maintaining a relatively high investment rate, particularly in housing and education (fig. 12). The output for Africa closely resembles that for Latin America, although basic needs are not met until 2008 and some shortfalls occur in the housing sector.

[46] Amilcar O. Herrera, *Proceedings of the 2d IIASA Global Modeling Conference* (Berlin, 1974), quoted by Meadows, Richardson, and Bruckmann, op. cit., p. 91.

[47] Hugo D. Scolnik, et al., "The Bariloche Model," in Meadow, Richardson, and Bruckmann, op. cit., p. 247.

[48] Jennifer Robinson, "The Latin American World Model," in *The Global 2000 Report to the President*, vol. 2, p. 647.

[49] Cole in *World Futures The Great Debate*, p. 48.

[50] Herrera, et al., op. Lit., p. 44.

[51] Robinson, "The Latin American World Model," p. 642

[52] Herrera, et al., op. cit., p. 8.

[53] Robinson, "The Latin American World Model," pp. 639, 643

[54] Herrera, et al., op. cit., pp. 87, 100-101.

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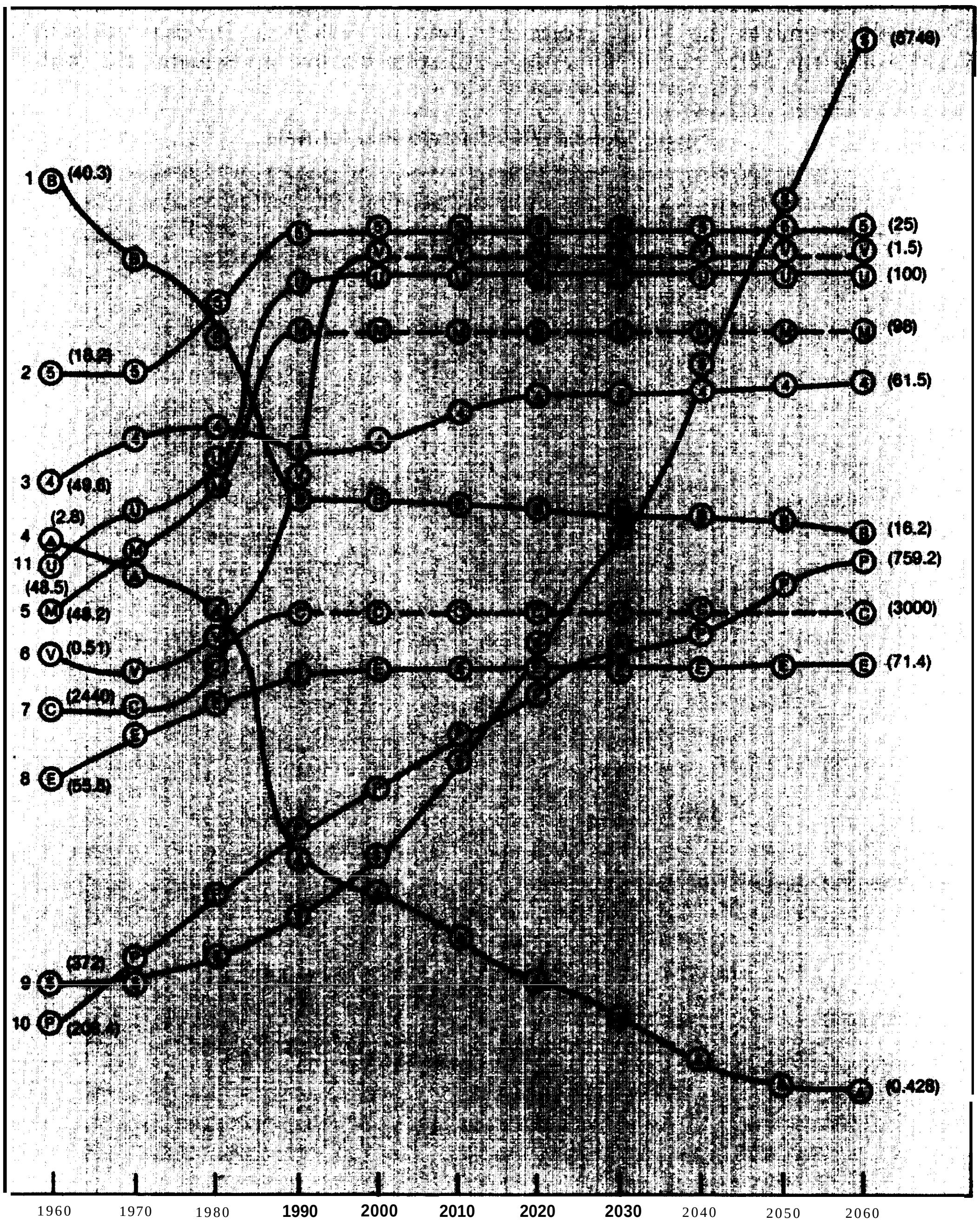
Figure 12.— LAWM Standard Run for Latin America



Key;

1 (B) Birthrate
2 (5) Percentage of GNP allocated to sector 5
3 (4) Percentage of GNP allocated to sector 4
4 (A) Population growth rate
5 (M) Enrollment
6 (V) Houses per family
7 (C) Total calories
8 (E) Life expectancy
9 ($) GNP per capita in 1960 dollars
10 (P) Total population
11 (U) Urbanization

SOURCE Catastrophe or New Society?

[Page Omitted]

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not keep up with population growth; daily food intake peaks at less than 3,000 calories per capita in 2008 and declines steadily thereafter. (These investments would also divert resources from the satisfaction of other basic needs, and they would probably prevent economic growth if investment in capital goods were not fixed at 25 percent.) Only an effective population policy and the use of nonconventional foodstuffs, both of which the authors advocate, could avoid catastrophe in Asia under these conditions.

The policy tests conducted with LAWM indicate that capital transfers from the industrialized countries (in isolation from other measures) would have little effect on the above outcomes, but they also reveal that both technological progress and internal income redistribution are vital to achieving regional goals.

- In the "international solidarity" run, the developed nations transfer capital aid to Africa and Asia at a rate that rises from 0.2 percent of GNP in 1980 to 2.0 percent in 1990 and thereafter. The result is higher investment rates and faster economic growth in the industrialized nations (in order to compensate for the aid), but very little effect on the time needed to satisfy basic needs elsewhere and a negligible impact on the food shortage in Asia.
- In the "technological stagnation" run, on the other hand, growth in economic production due to technical progress falls to zero between 1980 and 2000 and remains there. The outcome is disastrous in every region except the developed nations. Latin America requires a longer period of time to satisfy basic needs, particularly food and housing, and in Africa and Asia "the economic system finally collapses" sometime between 1990 and 2020 as population steadily outstrips production.
- By far the greatest difference in results, however, comes from the "historical" run, in which the assumption of egalitarian intraregional redistribution is replaced by a pattern of consumption that reflects current income distributions and socioeconomic structures. To satisfy basic needs in the same period of time under these conditions would require economic growth rates of 10 to 12 percent in the developing countries, rates which "are in fact impossible to attain. " The authors conclude that "at the very best" their goals would be delayed by two or three generations, and would require 3 to 5 times more resources, under these conditions.[55]

Conclusions of LAWM

The conclusions the LAWM team draws from its interactions with the model do not always reflect the above results (apparent discrepancies are noted in parentheses):[56]

- "it is possible to control population growth to the point of equilibrium by raising the general standard of living" (population stabilizes only in the developed regions, and is still growing globally at a rate of 1.1 percent per year in 2040);
- "if the policies proposed here are applied, all of humanity could attain an adequate standard of living within a period little longer than one generation" (this is true for Asia only with an effective population policy and considerable development aid);
- "this equilibrium could be achieved on a global scale well before the earth's capacity to produce food—the only foreseeable physical limitation within the time horizon of the model—is fully exploited even if food production continues to be based on currently available technology" (the model assumes considerable technical progress at no cost in agriculture and all other sectors, and fails to achieve its goals if technology stagnates);
- "[the] obstacles that stand in the way of the harmonious development of humanity are not physical or economic in the strict sense, but are essentially sociopolitical;" and
- "[the] goals are therefore [to be] achieved . . . by a reduction of nonessential consumption; increased investment; . . . the rational use of land . . . the egalitarian distribution of basic goods and services; and . . . the implementation of an active policy to eliminate deficits in international trade."

[55] Ibid., pp. 106-107.
[56] Ibid., p. 107.

United Nations Input-Output World Model— The Future of the World Economy

Origin and Purpose

Like LAWM, the United Nations Input-Output World Model (UNIOWM) represents a Third World reaction to the unpalatable conclusions of The Limits to Growth. However, its central concern is not the satisfaction of basic needs, but rather the narrowing of the income gap between the rich and poor nations. The model was commissioned in late 1972 by the Centre for Development Planning, Projections, and Policies (CDPPP), a U.N. agency responsible for long-range integrated planning. Initial financial support came from the Government of the Netherlands, and subsequent funding was obtained from the U. N., the Ford Foundation, and the National Science Foundation. Wassily Leontief, the project director, outlined the concepts behind the model in his acceptance speech for the Nobel Prize in economics in 1973; the work of collecting data and building the model was carried out by Anne Carter, Peter Petri, and others at Brandeis University. Petri presented the model at the Fifth IIASA modeling conference in September 1977, shortly after The Future of the World Economy was released in New York.

The study was conducted under U.N. auspices and direction. Although its findings did not represent official U.N. recommendations, the model's primary purpose was to determine whether physical or environmental limits would pose a significant barrier to the economic growth targets set by the U.N.'S International Development Strategy, which had been proposed by the General Assembly in 1970 as the basis for the Second Development Decade. As modified and expanded by various U.N. agencies, these targets include the following:

- reducing the average income ratio between the developing and developed countries by almost 50 percent, from 12:1 to 7:1;
- improving internal income distribution to eradicate mass poverty;
- creating 1 billion new jobs in the developing world by 2000;
- satisfying the basic needs of all people;
- increasing food production in developing countries by at least 4 percent per year; increasing the developing nations' share of the world market in manufacturing to 14.3 percent by 1985 and 25 percent by 2000; and
- achieving a new international economic order (NIEO), including stabilized commodity prices, increased financial and technology transfers, open markets for the less developed countries' (LDC) exports, and a code of conduct of translational enterprises.

Structure and Assumptions

The authors describe UNIOWM as "basically a general-purpose economic model and thus applicable to the analysis of the evolution of the world economy from other points of view, "[57] notably the environmental. However, Leontief has cautioned that:

> 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.
>
> To rule out internally inconsistent expectations we need to construct a model that guarantees internal consistency . . . by visualizing the world as a system of interdependent process in which each process . . . generates certain output and absorbs a specific combination of input.[58]

The rigorous accounting required by this input-output analysis forces the model to balance the growth of one economic sector against its effect on other sectors; similarly, imports and exports in one region must be balanced against the imports and exports of other regions. This technique also permits "an unusual degree of detail" in representing particular industries or regions, which is "advantageous" because of its "relatively specific policy significance. "[59] On the other hand, critics have

[57] Wassily Leontief, Anne Carter, and Peter Petri, *The Future of the World Economy: A United Nations Study* (New York: Oxford, 1977), p. 7.
[58] Wassily Leontief, "structure of the World Economy: Outline of a Simple Input-Output Formulation" (Nobel Memorial Lecture), *American Economic Review*, December 1977, p. 823.
[59] Leontief, Carter, and Petri, op. cit., p. 8.

questioned whether this level of explicit detail is worthwhile or justifiable, particularly since it demands an enormous amount of data, much of which had to be adapted from other information and data bases.[60] UNIOWM's population sector, for example, merely assumes the projections prepared by the U.N. Population Division in 1973 (see app. A).

The model divides the world into 15 regions composed of fairly homogeneous economies, although for purposes of interpretation and presentation of results these regions are further aggregated in three categories: developed nations (eight regions), resource-rich LDCs (three regions), and resource-poor nations (four regions). Each region's economy contains 45 sectors of economic activity, described by 175 equations with 229 variables. Prices are calculated in a separate submodel, and (as in LAWM) the representation of international trade has been kept "almost artificially simple. "[61] The environmental sector includes eight pollutants and five types of abatement activities, but the model does not reflect the effect of development on ecological systems, nor does it contain any other feedback loops; "it cannot, in any sense, be viewed as a dynamic model. "[62] The model's equations are solved simultaneously, usually at 5-year intervals, in order to provide "snapshots" of the world in 1980, 1990, and 2000.

The model can be applied to a wide variety of tasks, but its utility is limited by its large data requirements and by the many controversial assumptions that have been included. This has led one critic to conclude that:

> The huge number of assumptions made in estimating time trends for input-output matrices makes for confusion when it comes to considering the model as a whole. There are so many assumptions that one is hard put to evaluate the reasonableness of the total picture.[63]

Nevertheless, the model could be and has been used for a wide range of policy tests that reflect the interests of the modelers and the organizations that commissioned them.

Findings of UNIOWM

The study's optimistic findings, particularly that "no insurmountable physical barriers exist within this century to the accelerated development of the developing regions" and that "pollution . . . is a technologically manageable problem,"[64] received widespread attention in the media, where it was sometimes reported that UNIOWM "discredited" The Limits to Growth. However, the authors have cautioned that the model "cannot settle, and was not designed to settle, the many fundamental questions raised in The Limits-to-Growth debate."[65] And in fact the optimism of these general statements is not supported by the specific results of most of UNIOWM scenarios.

Policy tests conducted for the UN have included a number of different scenarios relating to economic growth rates and per capita income gaps.

- The "old economic order" scenario is based on historical trends in internal and external investment and existing international economic arrangements. Income per capita grows in all three categories of nations but income gaps increase, despite decelerating growth in the developed regions after 1990, and some LDCs would face an absolute decline in living standards (see fig. 14). This scenario "turns out to be rather pessimistic, " according to the authors, and because of its dim economic prospects for the developing regions it is "downplayed in the UN documentation. "[66]
- The standard run, based on the minimum growth targets of the International Development Strategy (IDS), also turns out to be relatively pessimistic. Because of their higher rates of population growth, accelerated economic growth in the LDCs does not lead to corresponding gains in GNP per capita. The income gap between developed and less developed regions remains at the current 12:1 ratio.

Sos am Cole, G/oba[LIo&/s and [he *International Economic Order A Paper for the UNITAR Project on the Future* (New York: Pergamon Press, 1977), p. 22; and Jennifer Robinson, "(J, N. World Model," in *The Global 2000 Report to the President*, ,01.2, p. 649

[61]Robinson, "U.N. World Model," p. 652.

[62]Meadows, Ric hardson, and Bruckmann, op. cit., p. 167; a similar criticism could be made of WIM.

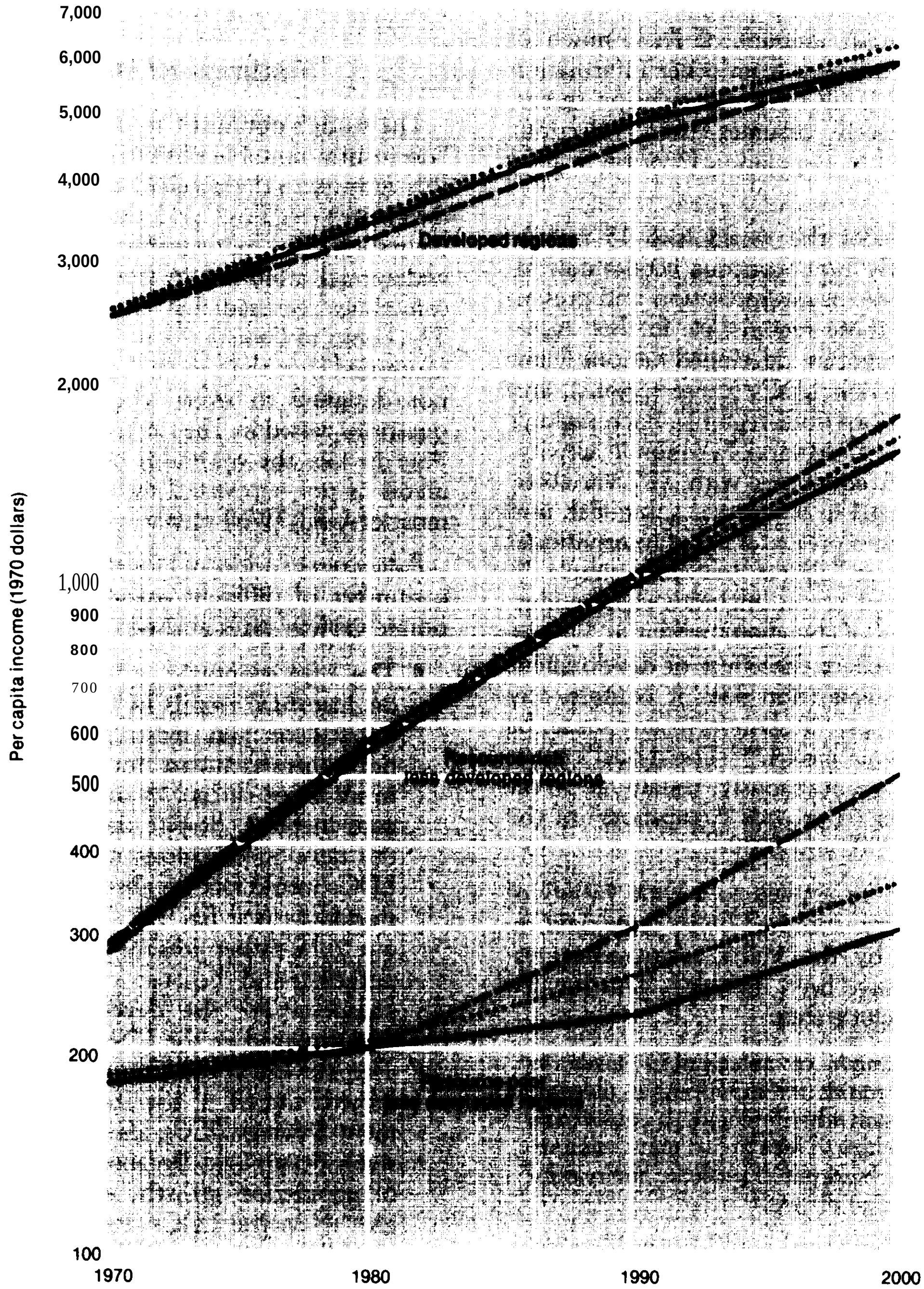
[63]Robinson, "U.N. World Model," p. 652.

6+ Leontief, Carter, and Petri, op. Cit., pp. 48-49.

[65]Peter Petri, "An Introduction to the Structure and Applications of the United Nations World Model," *Applied Mathematical Modeling*, vol. 1, No. 5, June 1977, p. 262.

[66]Leontief, Carter, and Petri, op. cit., p. 73; Robinson, "U N. World Model," p. 653.

Figure 14.—Regional Economic Growth Under Three UNIOWM Scenarios



Projected economic development of the developed regions of the world, the resource-poor less developed regions and the resource-rich less developed regions is shown to the year 2000 under the old-economic-order scenario (*solid black lines*), the new-economic-order scenario (*broken black lines*) and the arms-limitation scenario (*dotted lines*). For the resource-poor less developed regions the levels of per capita income and consumption (not shown) grow much faster under the arms-limitation scenario than under the old-economic-order scenario, but not so fast as under new-economic-order scenario, where income targets are prespecified.

SOURCE: Leontief, "The World Economy of the Year 2000," *Scientific American* 243.3, September 1980, p. 231.

- Four additional runs were then conducted by altering the standard or IDS scenario in such a way as to reflect more optimistic assumptions about: 1) resource endowments; 2) increased foreign aid from the developed regions; 3) fewer constraints on balance-of-payment deficits; and 4) faster agricultural investments to achieve food self-sufficiency in low-income Asia.

None of these scenarios, however, was capable of producing the desired reduction in per capita income ratios. In two final scenarios, therefore, the authors preset the model in such a way as to roughly halve the income gap by 2000 and close it completely by about 2050, and then solved its equations to determine the investment and growth rates that would produce the desired results:

- Scenario "C," based on the U.N.'s "low" population growth projections (see app. A), requires a 6.9 percent GNP growth rate in the LDCs to reduce the income ratio to 7.15:1 by 2000.
- Scenario "X, " based on the U.N.'s "medium" population projections, requires an even higher GNP growth rate of 7.2 percent in the LDCs and reduces the income ratio only to 7.69:1. Scenario "X" also requires a fivefold increase in overall agricultural output in the developing regions, including a nearly tenfold increase in resource-poor Latin America.

In subsequent policy tests, UNIOWM has been used to examine the economic consequences of mineral- and energy-conservation strategies. A study of the future production and consumption of nonfuel minerals, based on the resource conservation strategies of the Economic Council of Canada, is nearing completion but has yet to be publicly documented.[67] Another study, conducted for the U.S. Department of Commerce, compares the "old economic order" scenario with an "energy conservation" scenario based on the maximum reasonable reduction in fossil fuel consumption over the next 20 years through the substitution of labor and capital for energy. It revealed that energy conservation could reduce the balance-of-payments deficits of both developed regions and resource-poor LDCs and allow increased GNP growth in the latter, but that the capital requirements for conservation would require a 17- to 23-percent increase in the savings rate.[68]

More recently, Leontief has conducted two studies of the economic implications of the NIEO and of worldwide military spending, with funding from the U.N. and from American disarmament organizations.[69] In the NIEO scenario, the resource-poor LDCs are allowed to import whatever quantities of goods and services are required to reduce income ratios by 50 percent by the year 2000, with their balance-of-payments deficits–up to 75 percent of their imports—to be financed by "extraordinary credits" from the developed regions and resource-rich LDCs, carrying a nominal 5-percent interest rate. The model output for this scenario (see fig. 1.4) shows that the developed regions, which would have to ''work overtime . . . to provide [these] huge amounts of economic aid," would have a higher GNP but lower per capita consumption in 2000, at which time they would be allocating 3.1 percent of their total GNP to development assistance. Leontief himself doubts that such a plan could be implemented:

> On the whole this projection of the future development of the world economy under the new economic order suggests that the practical possibility of carrying out such an optimistic program must be seriously questioned.[70]

As an alternative, Leontief proposes an "arms limitation" scenario, noting that the current half-trillion-dollar annual worldwide defense spending represents "the largest existing economic reserve that might be utilized to accelerate the growth of the resource-poor less developed regions. " Where the "old economic order" scenario assumed that all regions would continue to devote the same percentage of their respective GNPs to defense that they had in 1970, the "arms limitation" scenario assumes that by 2000 the defense expenditures of the United States and the Soviet Union would be reduced by one-third, and that all other regions

[67] Meadows, Richardson, and Bruckmann, op. cit., p. 175; Robinson, "U.N. World Model," p. 653.

[68] Anne P. Carter and Alan K. Sin, "An Energy Conservation Scenario for the World Model," prepared for the Bureau of International and Economic Policy, U.S. Department of Commerce, November 1977, p. 2.

[69] Meadows, Richardson, and Bruckmann, op. cit., p. 175.

[70] Wassily W. Leontief, "The World Economy of the Year 2000," *Scientific American*, vol. 243, No. 3, September 1980, p. 230.

would reduce defense spending 25 percent by 1990 and 40 percent by 2000. The savings realized in each region would first be used to satisfy its own civilian needs, but the developed regions would allocate 15 percent of their savings to development aid by 1990 and 25 percent by 2000. The model output for this scenario (see fig. 14) indicates that per capita income and consumption in the resource-poor LDCs would increase far faster than under the old economic order. Since developed-region defense savings would be given to LDCs in the form of direct aid, their balance-of-payments deficits would also be far smaller. Based on a comparison of these scenarios, Leontief concludes that:

> .$. the reallocation of economic resources arising from the kind of international arms-limitation agreement that has been suggested repeatedly, both formally and informally by individuals and organizations inside and outside the U. N., is by far the most promising of the three schemes for world economic development .71

Conclusions of UNIOWM

The results of these numerous UNIOWM scenarios suggest, in general, that the economic prospects of the resource-poor LDCs are not very optimistic. The growth rate targets of the U.N.'s Second Development Decade are insufficient to begin closing the income gaps between developed and developing regions when population increases are taken into consideration. The limits imposed by mineral resources, agriculture, and the environment are not insurmountable and could be overcome through appropriate policies and investments; but "the principal limits to sustained economic growth and accelerated development are political, social and institutional in character."Tz To achieve accelerated development, therefore, two general conditions are considered necessary:

- far-reaching internal reforms in the LDCs including often drastic changes in sociopolitical institutions and economic policies—between 30 and 40 percent of GNP 'must be used for capital investment, particularly in the agricultural and export sectors, and both equitable income redistribution and increased public-sector participation are needed to increase the effectiveness of these investments; and
- significant reforms in the international economic order, aimed at reducing the potentially large balance-of-payments deficits in the developing regions—stabilizing commodity markets, stimulating exports of manufactured goods from the LDCs, and increasing financial transfers from the developed regions and resource-rich LDCs.

Neither of these conditions, taken separately, is sufficient to ensure a favorable outcome: [4]'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 of these conditions. "[73]

[71]Ibid., p. 231.

[72]Leontief, Carter, and Petri, op. cit., p. 48.
[73]Ibid., p. 11.

Global 2000—Entering the 21st Century

Global 2000 is a global modeling study, rather than a "global model" in the same sense that World 3, WIM, LAWM, or UNIOWM are. Its projections result not from a single, integrated model but rather from a collection of sectoral models, independently developed or adopted by various Federal agencies and other organizations, plus a number of projections based on analytical techniques other than computerized simulation models. Despite the very limited degree of interaction among the sectors and agencies, however, and despite the frequent lack of consistency in their various assumption and data bases, these sectoral "submodels" collectively provide the U.S. Government with the same type of projections that the other more integrated global models produce for their users.[74]

Origin and Purposes

Global 2000 was carried out by an interagency task force of the U.S. Government in response to a directive issued by former President Carter in his environmental message to Congress on May 23, 1977:

> Environmental problems do not stop at national boundaries. In the past decade, we and other nations have come to recognize the urgency of international efforts to protect our common environment.
>
> As part of this process, I am directing the Council on Environmental Quality and the Department of State, working in cooperation with . . . other appropriate agencies, to make a one-year study of the probable changes in the world's population, natural resources, and environment through the end of the century. This study will serve as the foundation of our longer-term planning. 's

This mandate, as interpreted by the Global 2000 task force, imposed dual objectives on the study: its purpose was not only to "identify [future] problems to which world attention must be directed," but also "to identify and strengthen the Government's capability for longer-term planning and analysis. "[76] The resulting report, released in July 1980, addressed both of these goals, although relying on the Government's existing capability may have detracted from the accuracy and usefulness of the resulting projections. According to a Science editorial:

> A reading of portions of the report produced after **3** years reveals more about the functioning of the federal government than it conveys new reliable information about the future of the world. "

Various Federal agencies are already conducting a considerable amount of long-term analysis and planning, and a number of them have the capability to produce projections based on extensive data bases and sophisticated sectoral models, many of them computerized. These existing tools and procedures (and the skilled personnel who use them) represent the "present foundation" of the Government's long-range global planning—they embody the assumptions on which current analysis is based, and they are actually being used as at least a partial basis for current planning and decision-making. As a result, the study plan chosen by the task force was "to develop trend projections using, to the fullest extent possible, the long-term global data and models routinely employed by the Federal agencies. "[78]

However, they found that "each agency has its own idiosyncratic way of projecting the future, " based on its individual planning requirements and area of responsibility .79 As a result, each agency's projections tend to focus on a single factor (such as population, food, or energy) without adequately considering the feedback involved in a system where these factors are interacting variables. Furthermore, although these separate projections "have generally been used by the Government and others as though they had been calculated on a mutually consistent basis, " the different agencies' models "were never designed to be used as part of an integrated, self-consistent system. "[80] This leads to one of the study's basic findings:

> To put it more simply, the analysis shows that the executive agencies of the U.S. Government are not now capable of presenting the President with internally consistent projections of world trends in population, resources, and the environment for the next two decades.[81]

Despite these deficiencies, Global 2000 presents the most comprehensive and consistent set of projections yet produced by the U.S. Government, and it represents the first attempt to make such

[74] Gerald O. Barney, study director, *The Global 2000 Report to the President: Entering the Twenty-first Century* (Washington, D. C.: U.S. Council on Environmental Quality and Department of State, 1980), vol. 3, pp. v-vi.
[75] Jimmy Carter, *The President's Environmental Program 1977* (Washington, D. C.: U.S. Government Printing Office, 1977), p. hi-l 1.
[76] Barney, *The Global 2000 Report to the President*, vol. 1, p. 6.
[77] Philip H, Abelson, "The Global 2000 Report," *Science*, vol. 209, No. 4458, Aug. 15, 1980, p. 761.

[78] *The Global 2000 Report to the President*, vol. 1, p. 6.
[79] Ibid., vol. 2, p. 454.
[80] Ibid.
[81] Ibid.

projections on a coordinated, integrated basis. The task force has been disarmingly frank and forthcoming in their analysis of "the Government's global model," and their discussion of its current weaknesses points to a number of ways in which existing long-range analysis and planning tools can be improved. Several of the models have in fact been modified or expanded in the last 3 years, often in response to problems identified by the task force, although many problems still remain.[82] The task force cautions, however, that "in the absence of ongoing institutional incentives to address cross-sectional interactions, the present form of the government's global model is not likely to change significantly in the foreseeable future."[83]

Structure and Assumptions

For the purposes of Global 2000, the study team imposed a "special limited discipline," within the time and resource constraints of the study, under which: 1) the assumptions, structures, and projections of the agencies' sectoral submodels were made "more mutually consistent" and 2) the output from one sector was used as the input for another "whenever this was readily feasible."[84] Despite these efforts, however, the Government's model has almost no feedback loops and remains at best "quasi-integrated," with the result that, "if anything, the severity of the effects of these basic trends may be understated."[85] In addition, the submodels employ different patterns of regionalization, varying from as few as five to as many as 28 regions, with a similar variation in the degree of detail provided.[86] This not only makes coordination difficult but also leaves the projections without a consistent geographic reference for policy analysis.

Furthermore, there are numerous major inconsistencies in the values assigned to the same variable in different sectoral submodels, reflecting mutually contradictory agency assumptions about the behavior of crucial factors.[87] The population sector, for example, assumes that birth rates in LDCs will decline because of continued moderate socioeconomic development, whereas the agricultural and economic projections indicate only marginal increases in global food and GNP per capita, with real declines in some LDCs—hardly reflecting moderate socioeconomic development.[88] Similarly, the GNP submodel assumes that the real price of wheat will *decrease* by 0.6 percent per year and that the real price of oil will remain constant during the early 1980's, whereas the food and energy projections indicate real price increases of 2.1 and 5.0 percent per year, respectively, over roughly the same period.

Far more serious, however, is the absence of any consistent accounting of capital or resource allocations in any of the sectoral submodels. This leads to what the report calls "significant omissions and double-counting'–in effect, the model recognizes no conflicts from competing demands or uses, and it places no constraints on the amount of capital and resources available to each sector.[89] Under these conditions, the same acre-foot of water is assumed to be available for both irrigation and energy development, just as the same barrel of oil is assumed to be available for transportation, energy generation, and petrochemical feedstock.

Different sectors also contain contrasting or contradictory assumptions about the course of public policy, despite the report's frequent repetition of the caveat that its trend projections are made *"under the assumption that present policies and policy trends continue without major change."*[90] The most significant exception to this rule comes in the population projections, which are based on the assumptions of: 1) continued socioeconomic progress despite marginal gains in food and GNP per capita in the LDCs; and 2) adoption of family planning policies in all countries and major extensions of existing programs, especially in rural areas. The other sectoral projections, however, are based on equally significant policy assumptions, including the following:[91]

[82] Ibid., vol. 2, p. 460 n. 2.
[83] Ibid., vol. 2, p. 461.
[84] Ibid., vol. 2, p. 457.
[85] Ibid., vol. 2, pp. 456, 481.
[86] Ibid., vol. 2, pp. 485 n. 1, 478; see also table 14-3, p. 479, and the methodological maps following p. 442.

[87] Ibid. vol. 2, pp. 461-476; see also table 14-2 and pp. 470-475 for an extensive discussion of "selected contrasting assumptions."
[88] Ibid., vol. 2, pp. 481-482.
[89] Ibid., vol. 2, p. 467.
[90] Ibid., vol. 2, p. 3; emphasis theirs.
[91] Ibid., vol. 2, table 14-2 and pp. 470-475; see also pp. 485-499.

- GNP.—Implementation of "prudent" policies to maximize export earnings, with GNP growth in the LDCs largely dependent on GNP growth in the developed regions;
- Food.—Major public and private investments in land development; a worldwide shift toward more fossil-fuel-intensive agricultural techniques and inputs; and (implicitly) improved resource management to protect fisheries and to prevent overgrazing, erosion, and farmland degradation;
- Energy.–Widespread deployment of light-water nuclear electric powerplants; implementation of more effective energy conservation programs in OECD countries; willingness of OPEC countries to meet oil demand up to their maximum production capacity; and major public and private investment in air pollution abatement so that by 1985 all countries' energy facilities are retrofitted to meet U.S. new-source performance standards for CO, SO_x, NO_x, and particulate; and
- Technology.–Major technological progress in almost 'all sectors, with no 'technological setbacks or adverse side effects; and extensive worldwide transfer and deployment of family-planning, yield-enhancing, nuclear-power, and pollution-abatement technologies.

In addition, the "no-policy-change" assumption itself explicitly excludes the possibility of either planned change or sudden upheaval in the world's existing political institutions and economic arrangements:

> . . . the Study assumes that there will be no major disruptions of international trade as a result of war, disturbance of the international monetary system, or political disruption. The findings of the Study do, however, point to increasing potential for international conflict and increasing stress on international financial arrangements. Should wars or a significant disturbance of the international monetary system occur, the projected trends would be altered in unpredictable ways.[92]

Findings and Conclusions of Global 2000

In the absence of more extensive policy testing, and because of the presence of contradictory and often controversial policy assumptions, Global 2000 does not provide an adequate basis for coordinated analysis or detailed policy recommendations. Furthermore, because of the omissions and inconsistencies outlined above, the study team concludes "that it is impossible to assign a high probability to any of the specific numeric projections presented" for its different sectors.[93] However, the current weaknesses and deficiencies of "the Government's global model" do not necessarily or completely invalidate its overall results, and the study team concludes that "these basic findings are qualitatively correct," since they are in general agreement with past projections by the same agencies, are supported collaterally by the alternative sectoral projections of outside organizations, and correspond "in . . . their most basic thrusts" with projections generated by "less complex but more highly integrated global models."[94]

Global 2000's often-quoted general conclusions about the future are as follows:

> If present trends continue, the world in 2000 will be more crowded, more polluted, less stable ecologically, and more vulnerable to disruption than the world we live in now. Serious stresses involving population, resources, and environment are clearly visible ahead. Despite greater material output, the world's people will be poorer in many ways than they are today.
>
> For hundreds of millions of the desperately poor, the outlook for food and other necessities of life will be no better. For many it will be worse. Barring revolutionary advances in technology, life for most people on earth will be more precarious in 2000 than it is now—unless the nations of the world act decisively to alter current trends.[95]

The principal sectoral findings on which these general conclusions are based, briefly outlined, are as follows:

- Population.—Global population growth rates will not decline significantly by 2000 and, in absolute terms, net population growth will be faster than it is today. The world's total population will increase by 55 percent, from 4.1 billion in 1975 to 6.35 billion in 2000, with 92 percent of the growth occurring in the LDCs, particularly in Africa and Latin America.

[92] Ibid., vol. 1, pp. 7-8.

[93] Ibid., vol. 2, p. 481.

[94] Ibid.

[95] Ibid., vol. 1, p. 1.

- GNP.—Worldwide GNP is projected to increase 145 percent during the 1975-2000 period, with faster annual growth in the LDCs (4.5 percent) than in the developed nations (3.3 percent), although growth rates in all regions will decline after 1985. Due to differential population growth, however, GNP per capita will grow much more slowly—an overall increase of only 53 percent worldwide, with marginal improvements or actual declines in a number of LDCs in Africa and South Asia. Existing income disparities between the richest and poorest nations will widen, and “dramatically different rates of change would be needed to reduce the gap significantly by the end of the century. ”[96]
- Food.—Worldwide food production is projected to increase by 2.2 percent annually from 1970 to 2000, a rate approximating the record increases of the Green Revolution. Since most of the good arable land is already under cultivation, most of this increase will come from more intensive use of energy-intensive inputs and technologies, resulting in an increased dependence on oil and gas and at least a doubling of real food prices by the end of the century. Since food production grows more rapidly than population, average per capita consumption will increase 15 percent worldwide by 2000, but with significant regional variations—increases of 21 percent in the developed regions but only 9 percent in the LDCs, with smaller increases in North Africa, the Middle East, and South Asia; and a “calamitous” 19. l-percent decline in Central Africa, where average caloric intake is already well below the minimum requirements set by the U.N. Food and Agriculture Organization. These projections suggest the need for food imports and food assistance will continue to grow in the developing regions, particularly in the poorest countries.
- Energy .-The energy projections, made in late 1977, indicate that world energy demand will increase 58 percent over the 1975-90 period. However, petroleum production capacity is not increasing as rapidly as demand, and the rate of reserve additions per unit of exploratory effort appears to be declining. As a result, technical considerations indicate that petroleum production will peak before the end of the century, although political and economic decisions by OPEC countries could cause production to level off even earlier. The resulting transition away from petroleum dependence is projected to be led by nuclear and renewable sources (primarily nuclear, but including hydro, solar, and geothermal), which are forecast to increase 226 percent by 1990; production of petroleum, natural gas, and coal is projected to increase by 58, 43, and 13 percent, respectively, over the same period. The projections also indicate considerable potential for reducing energy consumption per unit of economic production.
- Resource prices.–Global 2000 finds that the real prices of food, fish, lumber, water, and energy will increase significantly by 2000, with the steepest increases occurring after 1985. However, this finding shows how the nonintegrated model can lead to an economic paradox:

  > If the real prices of these commodities increase as projected, for what corresponding commodities will real prices decrease? If no compensating real-price decreases are projected, what do these “real” price increases mean theoretically—or even semantically? Unfortunately, even attempting to develop answers to these difficult questions would have exceeded the time and resource constraints of the study .[97]

- Environment.–Major strains will be placed on ecological systems throughout the world, leading to significant deterioration in terrestrial, aquatic, and atmospheric resources that would have adverse impacts on agricultural productivity, human mortality, and economic development. There are already signs of many of these effects, which will be felt more strongly, particularly in the LDCs, toward the end of the century. The projected increase in fossil fuel combustion could be expected to double the CO_2 content of the atmosphere by 2050, leading to a 2° to 3° C rise in temperatures and significant alterations in weather and precipitation patterns in the temperate zones,

[96] Ibid. vol 1 p. 13; compare with the discussion of UNIOWM, above.

[97] Ibid., vol. 2, p. 480 n. 1

where most of the world's food-exporting nations are located.

- Species extinctions.—Between 0.5 million and 2.0 million species of plants and animals could be extinguished by 2000, mainly through the loss of wild habitats or through pollution. This threat is particularly great in the tropical forests, which are an important potential source of new foods, pharmaceuticals, and building materials. An equally important threat is posed by the possible loss of local and wild varieties that are needed to breed pest-and disease-resistant traits into high-yield cereal grains.

Updates of these projections, developed on the basis of subsequent events or improvements in the forecasting tools, generally support the initial findings of Global 2000 and, if anything, provide even less reason for optimism:

- Fertility rates have declined more rapidly than expected in some areas, but world population in 2000 will be only 3 percent lower than originally projected.
- GNP projections are somewhat lower, due to increased petroleum prices and efforts to control inflation in OECD countries, with a consequent drop in LDC growth rates.
- Agricultural projections have also been revised downward, due to rapid increases in energy-related production costs and diminishing returns for other yield-enhancing inputs. In addition, increased concern with the consequences of intensive cultivation has led (in the United States and other developed nations) to pressure for resource-management policies that would prevent further erosion and soil deterioration. Some LDC governments are intervening in domestic markets to keep food prices low, often to the detriment of rural development and production capacity.
- The greatest differences are found in the energy sector: updated projections, reflecting the sudden large increase in oil prices in 1979, show that demand will be lower due to higher prices and slower economic growth caused by energy impacts in other sectors. Estimates of maximum OPEC production levels are lower, reflecting the cartel's resource-conservation policies. Estimates of future OECD nuclear capacity are also lower, reflecting construction delays and public concern as well as the U.S. licensing moratorium, and coal is projected to provide a larger share of energy supplies. Higher prices are also expected to encourage the adoption of alternative sources (including solar) and conservation measures.

CHAPTER 3

Findings of the Global Models

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Findings of the Global Models

Introduction

The five global modeling studies addressed in this report demonstrate at least three fundamentally different "predictive styles' '—World 3 and Global 2000 examine what might happen if present trends continue, while the Latin American and United Nations (U. N.) world models examine the goals that might be achieved through broad changes in those trends, and the World Integrated Model (WIM) examines the policies and actions that might bring those changes about.[1] The models also vary significantly in their more specific purposes, assumptions, and methodologies. In addition, they focus on different parts of the world system, at different levels of detail, and over different spans of time. These fundamental differences, as well as the more specific differences in patterns of regionalization and degrees of aggregation, make it difficult to compare their projections in any extensive or sustained manner.

[1]See Stuart Bremer, "Testing Models," in Donella H. Meadows, John Richardson, and Gerhart Bruckmann (eds.), *Groping in the Dark*: The First *Decade of Global Modeling* (New York: Wiley, forthcoming), pp. 376-377.

The five models nevertheless display a limited consensus about the nature of the world system and the identity of the problems facing it, as well as some of the steps that might be taken to address them. The following discussion will examine the areas of general agreement or disagreement that emerge from these five studies, first in their qualitative conclusions about the general problems of the world future, and then in their quantitative findings in three key sectors: population, food, and energy. Extended technical analysis of their projections in these three key sectors and of the structural differences between the models is provided in the appendixes.

Qualitative Conclusions About the World and Its Future

Despite the many differences between these five global models, it is possible to draw a number of common themes from them about the present state of the world and the possible paths it might follow in the future. The following statements are based on a list compiled by Donella Meadows, John Richardson, and Gerhart Bruckmann for a forthcoming review' of the first decade of global modeling.[2] The statements reflect a number of qualitative findings with which (according to the authors) almost all global modelers would agree, and they are arranged in such a way as to form a loose logical argument:

- Population and physical (material) capital cannot grow indefinitely on a finite planet.
- There is, however, no reliable or complete information about the planet's ultimate carrying capacity. * There is a great deal of partial information, which optimists read optimistically and pessimists read pessimistically.
- Nevertheless, there is no known physical or technical reason why the basic human needs* of all the world's people cannot be supplied now and into the foreseeable future, These basic needs are not now being met because of political, economic, and social factors, not because of overall physical scarcities.
- Continuing "business *as* usual" policies over the next few decades will not lead to the best possible outcome, nor to a desirable outcome, nor even to the satisfaction of basic human needs. It would result instead in an increasing gap between the rich and the poor, worsening economic conditions, growing international tension, problems of resource availability, and environmental degradation.

[2]Meadows, Richardson, and Bruckmann, op cit., pp 18- 19, 49-50; see also John M. Richardson, jr., "Towards Effective Foresight in the United States Government" (prepared for the U. S. Department of State, June 1979), pp 5-6 and app. C.

*The terms "carrying capacity" and "basic human need" are highly value-laden and therefore inescapably lead to debate.

- Because of these difficulties, the continuation of current trends is not a likely future course. Over the next three decades, therefore, the world's socioeconomic system will be in a period of transition to some new state that will be both quantitatively and qualitatively different from the present.
- The exact nature of this future state, and whether it will be better or worse than the present, is not predetermined—it is a function of decisions and changes being made now.
- Because of the momentum inherent in the world's physical and socioeconomic processes, policy changes that are made soon are likely to have more impact with less effort and cost than the same set of changes made later; and if the changes are put off for too long, they may not work at all.
- Changes in technology are expected and indeed essential: even the most optimistic scenarios might fail if technological progress is inadequate. However, no set of purely technical changes tested in any of the models was sufficient in itself to bring about a desirable outcome. The models suggest that restructuring social, economic, and political systems will also be necessary and may in fact be more effective.
- The interdependencies among peoples and nations, over time and space, are far greater than commonly imagined: actions taken at one time in one part of the world have far-reaching consequences that are often difficult to anticipate intuitively and are probably impossible to predict (totally, precisely, perhaps at all) even with computer models.
- Because of these interdependencies, isolated measures intended to reach narrowly defined short-term goals are likely to be less effective than anticipated. Decisions should therefore be made within the broadest possible context, across space and time and intellectual disciplines.
- As a further consequence of these interdependencies, cooperative, long-term approaches to achieving individual or national goals often turn out to be more beneficial to all parties than short-term, competitive approaches.
- Many existing plans, programs, and agreements—particularly complex international ones like the U.N.'s International Development Strategy—are based on assumptions about the world that are either mutually inconsistent or inconsistent with physical reality. Much time and effort have thus been spent in designing and debating policies that are in fact simply impossible.

In short, according to the authors, the modelers generally agree that the world system is going to change in the near future, and that a continuation of current trends and policies will lead to a change for the worse. They also agree that changes for the better are possible, although they disagree sharply on what those changes should be and which policies would bring them about. In the authors' words, the models indicate that "we should do something, [but] we can't be sure what we should do."[3] Environmentalism and the Club of Rome's "world problematique" (see below) seem to have influenced the earlier models, which stressed the limits of the present system and called for an "equilibrium state" or "organic growth." The more recent models, which stress the *inequities* of the present system and call for internal and/or international redistribution of growth and consumption, seem to have been influenced more directly by the issues surrounding the "new international economic order."

In spite of these differences in emphasis and prescription, however, general agreement does emerge about the fundamental issues or "problem nexus" for which projections must be made and solutions found.[4] The following sections, therefore, summarize projections made by the five global models in three of these crucial areas:

- population, which is addressed by all of the models and is the most fundamental driving variable in most of them;
- food supply, the most basic of human needs and the most promising basis for comparisons between the models; and
- energy, which reflects the more general problems of resource depletion but has a uniquely important impact on agriculture and economic activity.

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[3] Meadows, Richardson, and Bruckmann, op. cit., p. 51,
[4] Bremer, op. cit., p. 375.

The purpose of these summaries is not to arrive at a "consensus projection, " but rather to illustrate the similarities and differences among the models. More detailed information and technical analyses can be found in the historical survey and appendixes.

Population Projections

Table 2 shows the results of a number of studies of future population growth, including three that did not employ global models. Population projections play a key role in any assessment of future world conditions, since the size of the population will determine the number of consumers of goods and services and the number of people available to produce those goods and services. In some global models, the future size of the population is projected without regard to changes in other conditions; in others, population growth projections are affected by other factors such as technology or economic development. These structural differences, combined with uncertainties about the present size and future behavior of the world's population, lead to variations in the projections themselves and differences in their reliability and usefulness to the policy maker. Reliability is also affected by time horizon, which in turn reflects one of two basic goals:

- to provide an accurate short-term (25 years or less) forecast of world conditions; or

[5]The following discussion is highly condensed; see app. A for a more detailed comparative analysis of population projections. For further Information on this topic, see OTA's assessment, *World Population and Fertility Planning Technologies: The Next 20 Years*, OTA-HR-157 (Washington, D. C.: U.S. Government Printing Office, February 1982).

Table 2.—Comparison of Short- and Long-Term Population Projections

Model or source	Scenario or projection	Population in 2000 (billions)	Longer term projections
World 3	Standard run	6.0	Population increases to 7.0 billion by 2025, then decreases to 4.0 billion by 2100
	Equilibrium run	NA	Population stabilizes at 6.0 billion by 2050
World Integrated Model	Standard run	6.4	Population stabilizes at just under 7.0 billion by 2015. Death rates due to starvation are high in South Asia
Latin American World Model	Standard run	6.4	Population reaches 11.0 billion by 2040 and is still growing at 1.1 percent/yr. Death rates due to starvation rising rapidly in Asia
	Second run (improved conditions in Asia)	NA	Population reaches almost 11.0 billion by 2060 and is growing at less than 0.5 percent/yr
United Nations	1978 assessment (provisional)	5.9 to 6.5	Population reaches 8.0 to 12.0 billion by 2050 and stabilizes at 8.0 to 14.0 billion by 2150
Global 2000 (Census Bureau)	High, medium, low	5.8 to 6.5	NA
CFSC	High, medium, low	5.8 to 6.0	Population reaches 7.8 to 8.1 billion by 2050 and is virtually stationary
World Bank	Standard	6.0	Population stabilizes at 9.8 billion by 2175
Harvard	Standard	5.9	Population reaches 8.4 billion by 2075 and is virtually stationary

SOURCE: The Futures Group.

- to describe the long-term behavior of the global system.

Findings

There is relatively little variation (plus or minus about 5 percent) in the population projections for 2000, which range from a low of 5.8 billion to a high of 6.5 billion. This reflects the higher degree of certainty inherent in population projections for periods under 25 years: there is relatively little uncertainty about the number of reproductive-age females between now and 2000, although there is more uncertainty about the number of children each will bear. The global models that aim for this sort of accurate, short-term forecast (the United Nations Input-Output World Model (UNIOWM) and Global 2000) are based primarily on expert judgments about changes in fertility and mortality. As a result, population is linked to other conditions only to the extent that the experts consider the rest of the world system when they make these judgments. This short-term approach strives for accuracy and usefulness by making separate projections for individual countries, which can be summed to produce a world total.

The long-term global modeling studies (World 3, WIM, and LAWM) attempt to describe the general behavior of the entire global system over the next 50 to 125 years, and they consider population as only one of many factors in dynamic, integrated system behavior. The level of accuracy that is sufficient for this purpose is quite different from that sought in the U.N. or Census Bureau projections. However,, the difficulty with this approach is that the relationships between fertility, life expectancy, and the factors that affect them—such as food production, pollution, and economic and social development—are not known, nor is the historical evidence rich enough to allow these relationships to be estimated with any degree of confidence.

As a result, long-range models are more speculative and their population projections show considerably more variation. Two differences in table 2 are particularly notable. In World 3, population actually begins to decline due to increasing death rates after 2025, and presumably would do so for Asia in WIM and LAWM if they were extended beyond 2060. All of the other projections show population growing more slowly until it reaches some stationary level. However, there are immense variations in the size of that stationary population, which ranges from a low of 8 billion to a high of 14 billion.

Limitations

The reliability of the projections, and their usefulness to the policy maker, are also influenced by a number of theoretical and data constraints and by the policy assumptions that have been built into the global models. As mentioned above, there is neither theoretical agreement nor sufficient historical evidence about the relationships between population variables and conditions in the rest of the world system. There is also considerable uncertainty in the base-year data for the initial population figures—estimates of China's population vary by as much as 14 percent, for instance, and the current population of Nigeria has been estimated at anywhere between 65 million and 85 million.

These differences in base-year estimates tend to cancel out when they are summed at the global level, and the recent round of censuses has substantially improved the information available for many countries, particularly in Africa. However, there is still uncertainty about present rates and future changes in fertility and life expectancy, resulting from at least four factors:

- uncertainty about how much birth rates have already declined;
- uncertainty about the contribution of existing family planning efforts and technologies to past declines in birth rates;
- uncertainty about how many countries will adopt family planning programs, and uncertainty about how strong or effective these efforts will be; and
- uncertainty about the relevance of past experience with family planning to those countries that have little experience with such programs, notably in Africa.

Different global models contain different assumptions about the above factors as well as about other policy decisions, all of which may have some effect on future changes in population growth. The short-range models that use exogenous population figures also seem to assume that current trends will continue unchanged (at least until 2000), thereby excluding such disasters as international conflict and massive starvation. The long-range models, on the other hand, suggest that regional or even global disasters are increasingly likely in the longer term. World 3 and LAWM point out the dangers of inaction and delay and suggest alternatives to present trends, but neither model has adequate mechanisms for testing specific policy options. WIM, which was designed as a policy tool, is both more flexible and more disaggregate. The more detailed stand-alone projections, like those used in UNIOWM and Global 2000, can become a valuable input to further analysis for developing policy options, testing development goals, and planning broad strategies for the world future.

Agricultural Projections

The world food problem has been a major concern for global modelers. All of the well-known models have one or more agricultural sectors; all consider measures of food availability to be major indices of system performance; and all indicate that the performance of the global agricultural system over the next 20 to 100 years is a matter of major concern. Table 3 compares the projections for key agricultural variables in 2000 generated by four global models and by two large-scale agricultural models, the Model of International Relations in Agriculture (MOIRA) and the Grain-Oilseed-Livestock model (GOL) used for Global 2000.

Findings

In general, the most optimistic food supply projections come from assumptions of rapid economic growth and technical progress, slow population growth, and large reserves of easily developed agricultural land. There is far greater variation in regional projections than in global projections; the most severe problems are foreseen in South Asia and Sub-Saharan Africa. The results are also highly dependent on time horizon—longer time horizons generally lead to more pessimistic findings.

All of the models except UNIOWM indicate that there will be problems in supplying food to at least some of the world's people over the next 20 years. The reason for this finding is fairly straightforward: all of the models except UNIOWM assume diminishing marginal returns to agricultural inputs and increasing costs for land development as the amount of undeveloped land decreases; in short, the models show agricultural problems because they include agricultural limits. Similarly, WIM's relatively pessimistic estimates of potentially arable land, which are 25 to 30 percent lower than the other models, undoubtedly contribute to its dire predictions of impending famine in the developing regions.

Price projections (for the models that make them) vary far more than supply projections, with

[6] The following discussion is highly condensed; see app. B for a more detailed comparative analysis of agricultural projections. For further information on this topic, see OTA's forthcoming assessment, *Impacts of Technology on Productivity of Rangelands and Croplands*, OTA-F-166 (in press).

Table 3.—Percentage Increases in Projected Global Food Production, Food Prices, and Food per Capita, 1970-2000

	World 3	World Integrated Model	Latin American World Model	U.N. Input-Output World Model	MOIRA	Global 2000 GOL Model
Food production	160	NA	NA	179[a]	85-144[b]	91-98[b]
World market price	NA	NA	NA	14	13-422[b]	30-115[b]
Global food per capita	9	NA	NA	56[a]	8-40[b]	4-26[b]

[a] Average of grain and livestock products.
[b] Reflects difference between low-growth (pessimistic) and high-growth (optimistic) scenarios.
NA—Not calculated.

SOURCE: Office of Technology Assessment.

real increases ranging from 13 to 422 percent by 2000. MOIRA, which assumes that farmers will increase production to maximize their profits at a given price for agricultural inputs, concludes that measures that drive food prices up will be a successful means of reducing world hunger. However, profit maximization may be a better approximation of the behavior of rich farmers than that of poor farmers, who may not be able to borrow funds to expand production, or who may resist giving up their traditional agricultural practices. For this reason, MOIRA may overestimate the response to price incentives in the developing countries (see app. B). World 3, LAWM, and UNIOWM all lack price mechanisms, and none of the six models takes the international monetary system into account.

Technical Progress

World 3 assumes that most increases in agricultural production will come from increases in land under cultivation; Global 2000 assumes that they will come from increased yields per acre; and UNIOWM, the most optimistic of the models, assumes both increased cultivation and increased yields. All of the models except World 3 also include some form of "disembodied technological progress' '—income growth not attributable to increases in capital, labor, or other inputs—which amounts to an assumption that agricultural productivity will increase automatically at no cost. The rate of such progress is 1.0 percent per year in LAWM but is unreported for the other models, despite the fact that model results are highly sensitive to its presence and magnitude. When technological progress is eliminated from LAWM, for example, Africa as well as Asia faces land constraints and economic collapse. In World 3, on the other hand, sufficiently strong assumptions about technological progress can eliminate the overshoot-and-collapse mode entirely.

Uncertainties

Population and income growth are calculated independently from food supply in MOIRA, UNIOWM, and Global 2000. The effects of pollution on agricultural yields is omitted in all of the models except World 3 and UNIOWM. These factors have an important influence on model results, as do assumptions about the availability and price of inputs such as fertilizer, irrigation, and farm machinery, but there is little agreement among the models on the values that should be assigned to them. Nor does any of the six models account for several trends that are likely to affect agriculture in the coming decades:

- regional or sectoral competition for water supplies;
- unusually bad weather, including adverse long-term climatic changes;
- Increased productivity due to advances in genetic engineering; and
- potential shrinkage or destabilization of oil and gas supplies.

Energy Projections

The future availability and price of energy resources are crucial variables in long-term projections of world economic development. However, some of the models do not address energy specifically or in detail, and the findings of those t-hat do are significantly influenced by their assumptions about the global energy system and future energy trends. In general, those models that include a finite resource stock tend to show that depletion will raise prices, slow industrial production, and dampen global economic growth. In short, as with agricultural projections, they predict energy problems because they include energy constraints.

Findings

Collectively, the models indicate that the world faces a near-term transition away from dependence on conventional sources of petroleum and

The following discussion is highly condensed; see app. C for a more detailed comparative analysis of energy projections. For further information on this topic, see OTA's technical memorandum, *World Petroleum Availability 1980-2000*, OTA-TM-E-5 (Washington, D. C.: U.S. Government Printing Office, October 1980), and the OTA assessment, *Technology and Soviet Energy Availability*, OTA-ISC-153 (November 1981).

natural gas, and that the major alternatives among which future energy choices must be made are coal, nuclear, and solar power. The models whose projections extend farthest into the next century indicate that coal, conservation, and conventional nuclear power may not be enough to sustain continued economic growth. Breeder reactors, fusion, and large-scale solar power may therefore be necessary.

In World 3, rising extraction costs are the principal cause of economic collapse. As an increasing percentage of capital is allocated to obtaining nonrenewable resources, investment and productivity decline in agriculture and other sectors. New mining technologies and nuclear power can delay but cannot prevent a global economic collapse.

WIM, on the other hand, finds that collapse due to costly resources is less likely than a future based on widespread deployment of breeder reactors, but it also examines an alternative based on large "solar farms" in the deserts of the Middle East. This model is perhaps the most flexible in dealing with energy choices, and it has been used in a variety of policy tests focusing on energy prices and the behavior of both producers and consumers.

LAWM explicitly excludes the problem of energy and other resources. The authors assume that conventional fission and the potential development of fusion power will eliminate the global energy crisis without significantly raising prices.

UN1OWM, because of its restricted time horizon, foresees "[no] problem of absolute scarcity in the present century. " However, the model does project a 77-percent depletion of conventional oil reserves by 2000. Its optimism about future energy supplies is based primarily on abundant coal supplies (it projects a decline in the real price of coal despite a 400-percent increase in demand) and on the assumption that nuclear power will generate an increasingly large share of the world's electricity.

Global 2000's energy projections indicate a supply-constrained oil market before 1990, with production declining thereafter. As a result, "a world transition away from petroleum dependence must take place. " Global 2000 examines several potential energy systems, but foresees nuclear power and coal as the most likely alternatives. It also foresees considerable potential for "conservation-induced reductions in energy consumption. "

Limitations

The accuracy and reliability of these projections are affected by their assumptions about a number of physical, technical, and economic factors:

- the total reserves of each resource;
- the rates of population and GNP growth;
- the degree to which energy demand growth will be moderated by conservation or substitution among sources;
- the bottlenecks involved in mobilizing additional or alternative energy sources; and
- potential energy breakthroughs such as fusion and solar power.

CHAPTER 4

Global Models and Government Foresight

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CHAPTER 4

Global Models and Government Foresight

Introduction

The "futures debate" of the last 15 years has taken place against a background of rapid and sometimes unexpected changes in national and world affairs, including:

- a general slowdown in the rapid economic growth that had characterized the world economy since World War II, leading to stagnation in the industrialized nations and stalled development in the less developed countries (LDCs);
- rapid population growth and urbanization in much of the Third World, leading in some cases to widespread hunger, social unrest, and political instability;
- structural changes in the world's political and economic systems, typified by the emergence of OPEC and new nuclear powers and by Third World demands for a "new international economic order;"
- growing apprehension about the cost and continued availability of natural resources, best exemplified by the energy crisis; and
- increasing concern for the regional and global environmental consequences of continued industrialization.

These and similar developments have shown that long-term global trends can have serious implications for the economic and national security interests of the United States. This in turn has led to proposals in Congress and elsewhere that the U.S. Government should improve its "foresight capability "—its institutional capacity to project long-range global trends and their consequences, and to use these projections as inputs in the process of strategic assessment, policy development, and decisionmaking. A number of Federal agencies are already using global models and other computerized models as tools of long-range analysis and planning, but the Government's present capability is limited by unevenness of data, inconsistency of assumptions, and lack of proper coordination. * If existing deficiencies are corrected, global models could become a more effective tool in four specific areas:

- assessing the potential future impacts of current trends, policies, and decisions;
- monitoring the national and international situation to identify early signs of potential problems or opportunities;
- formulating and evaluating a wide range of alternative policies and courses of action for achieving national goals, avoiding potential problems, and exploiting potential opportunities; and
- providing a framework to ensure consistency between short- and long-term analyses and across agency jurisdictions.

[1]For specific details, see the discussion of the *Global 2000 Study* in ch. 2 and the appendixes. Examples of previous Government uses of models and comparisons with traditional long-range analytic and planning techniques can be found in the following sources:

- *A Guide to Models in Government Planning and Operations* (Washington, D.C.: U.S. Environmental Protection Agency, 1974);
- *Federally Supported Mathematical Models: Survey and Analysis* (Washington, D.C.: National Science Foundation, 1974);
- *Computer Simulation Methods to Aid National Growth Policy*, prepared for the Subcommittee on Fisheries, Wildlife Conservation, and the Environment of the House Committee on Merchant Marine and Fisheries (Washington, D.C.: Library of Congress, Congressional Research Service, July 1975);
- *Long-Range Planning*, prepared for the Subcommittee on the Environment and the Atmosphere of the House Committee on Science and Technology (Washington, D.C.: Library of Congress, Congressional Research Service, May 1976);
- Joint Economic Committee, *U.S. Economic Growth From 1976 to 1986: Prospects, Problems, and Patterns*, 12 vols. (Washington, D.C.: U.S. Congress, 1976-77), especially vol. 2, *The Factors and Processes Shaping Long-Run Economic Growth*, vol. 6, *Forecasts of Long-Run Economic Growth*, and vol. 7., *The Limits to Growth*; and
- *The Use of Models for Water Resource Management, Planning, and Policy* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, forthcoming).

Benefits of Global Models

The essential claim for global models is that they represent the behavior of the real global system, or at least some of its components, in ways that are superior to the less formal mental models and forecasting techniques currently being used by decisionmakers, policy analysts, and the general public.[2] Their benefits are those of mathematical models in general and computerized models in particular, the difference being that global models are specifically designed to address problems and issues of a global scale and importance. This can make them a valuable tool of analysis and a valuable additional input to policy development and decisionmaking. Specific benefits of global models include the following.[3]

- Longer time horizon.—Many current forecasting techniques are used primarily for annual or short-term projections, whereas global models typically have time horizons of 20 years or more. This allows them to assess long-term effects and cumulative changes, however critical, that might not otherwise be detected.
- Comprehensiveness.—A computerized model can contain far more information about the world system than any single mental model. It can also keep track of many more variables and interrelations at the same time and, according to some modelers, it is far more sensitive to subtle, remote, or counterintuitive effects and outcomes.
- Rigor.—They impose a logical discipline by requiring the modelers—and the model users—to make explicit, precise, and complete statements of their objectives, assumptions, and procedures. The system or process being modeled must be clearly divided into its major components, and the relations between those components must be specified. This procedure may lead modelers and model users to revise their mental models—or to refine them by identifying previously ignored components and relations—even before computer analysis begins.
- Accessibility.-The assumptions and structure of the model must be written out before they can be run on the computer. This allows all sides to examine them, point out omissions or inconsistencies, and suggest improvements. Open communication about both the system and the model can lead in turn to the incorporation of fresh insights and differing viewpoints.
- Logic.-If properly designed and programed, a computerized model will draw logically correct and mathematically error-free conclusions from an extremely complicated set of assumptions and data. This can lead to novel insights into unexpected or counterintuitive system behavior, reveal areas in which further research is needed, and expose assumptions that are inconsistent or contradictory.
- Flexibility and range.–By making small changes in the magnitude and relations of variables, it is possible to examine the implications of a wide range of alternate assumptions and to test the sensitivity of the outcome to changes in different parameters. The models can also be tailored to "fit" particular problems, regions, or issues. The model can therefore become a powerful planning tool, and properly updated runs can be used to monitor program progress.
- Instructiveness.–The flexibility of global models also makes them a valuable tool for analysts, planners, and policy makers alike, allowing them to examine a broad range of possible outcomes, responses, and policy options. This can allow them to reject physically impossible options, clarify the nature of various risks, and evaluate the adequacy of different options for minimizing those risks. Thus, even when the models cannot give precise quantitative answers, they allow the users to sharpen their analytic skills and improve their intuitive "feel" for the operation of the system.

[2] L. M. Ward, et al., "World Modeling: Some Critical Foundations," *Behavioral Science*, vol. 23, No. 3, May 1978, p. 138.

[3] See Donella H. Meadows, John Richardson, and Gerhart Bruckmann (eds.), *Groping in the Dark: The First Decade of Global Modeling* (New York: Wiley, forthcoming), pp. 20-21, 42-43, 203, 310-312; and Dennis L. Little, et al., Long-Range *Planning* (Washington, D.C.: U.S. Library of Congress Congressional Research Service, 1976), prepared for the Subcommittee on the Environment and the Atmosphere of the House Committee on Science and Technology, pp. 456-457.

Limitations of Global Models

Despite these benefits, global models remain subject to a number of limitations that may constrain their accuracy, reliability, and usefulness for policy making:[4]

- Theoretical limitations.–The structures of different global models are based on underlying assumptions adapted from systems analysis and several other disciplines, including engineering, economics, and the natural sciences. There is no general agreement on the relative validity of their competing explanations of socioeconomic phenomena, nor is there any evidence that one approach produces results that are consistently more reliable than the others. In addition, theoretical understanding of a number of important processes (for example, the effect of socioeconomic conditions on fertility rates) is too weak to allow adequate modeling, although projections based on alternative assumptions can still be useful and instructive.
- Methodological limitations.–The essence of modeling is a simplification that improves understanding, but this means that a limited number of discrete factors and relations must be used to describe the dynamic complexity and ambiguity of the real world. Theoretical bias and data constraints often determine which variables and relations are included or omitted, but no model could include every factor without becoming as complicated as the real world.
- Data limitations.—Data vital to proper forecasting are often nonexistent, inaccessible, or unreliable. This is particularly true for environmental data and for most data on the LDCs. This situation has improved somewhat in recent years, but data limitations remain a serious constraint on reliability and on the sectoral and regional coverage that models can achieve. In some cases there are inadequate empirical data on which to base improvements in theoretical understanding.
- Practical limitations.–An effective global modeling effort requires considerable time, an interdisciplinary team of modelers and technicians, a large and continuously updated data base, access to computers of sufficient capacity, support services, and money. Skimping on any of these requirements greatly increases the risk of error and unreliability in the resulting forecasts.

4See Meadows, Richardson, and Bruckmann, op. cit., pp. 22, 43-44, 312-313; Little, et al., op. cit., pp. 458-459; Ward, et al., op. cit., and *The Global 2000 Report to the President*, vol. 2, ch. 14.

Institutional Opportunities and Barriers

Since President Theodore Roosevelt created the National Conservation Commission in 1908, numerous presidential and congressional committees, commissions, task forces, and studies have recommended in one way or another that the U.S. Government should improve and/or institutionalize its long-range analysis, planning, and policy-making capability. The most recent study discussed in this report, The Global 2000 Report, reveals that, individually, the executive agencies possess an impressive, if uneven, capability for long-range analysis and forecasting within their separate areas of responsibility and interest; but it also reveals "that, collectively, the executive agencies of the government are currently incapable of presenting the President with a mutually consistent set of projections of world trends in population, resources, and the environment. "[5] Nevertheless, according to the report, "Important decisions—involving billion-dollar federal programs and even the national security—are partially based on these projections, " which "have generally been used by the government and others as though they had been calculated on a mutually consistent basis."[6]

5*The Global 2000 Report to the President*, vol. 2, p. 3
6Ibid., vol. 2, p. 45-I.

The interagency followup report, Global *Future: Time to Act*, carries these conclusions a step further:

> If there is one clear lesson from the exercise of putting the *Global* **2000** Report together, it is that the U.S. government currently lacks the capacity to anticipate and respond effectively to these global issues. . . . As of today, the government still does not adequately: 1) project and evaluate future trends; 2) take global population, resource, and environmental considerations into account in its programs and decisionmaking; and 3) work with other countries to solve these problems. T

The deficiencies in the Government's current foresight capability appear to be institutional rather than technical. In a recent analysis of the potential Government policy applications of computer models, A. D. Little found modeling to be potentially quite useful:

> Current state-of-the-art techniques in long-range forecasting of population, resources, and the environment present significant opportunities for the State Department to enhance its capabilities for analysis of the long-run future socioeconomic and political consequences of foreign national demographic, resource, and environmental conditions.[8]

After considering the various limitations of computerized modeling (see above), the A. D. Little report concludes that "Institutional conditions are often much more of a constraint to the effective use of forecasting models than methodological or data considerations."[9] These findings, although addressed to the Department of State, would appear to be equally relevant to the modeling activities of other agencies and of the Government as a whole.

The *Global* 2000 Report includes similar findings—the discrepancies and lack of integration among its forecasts arise:

> . . . essentially because of the institutional context in which the elements of the model were developed and are being used, This context emphasizes sectoral concerns at the expense of interactions among the sectors and leads to distorted and mutually inconsistent projections. 10

[7]Nicholas Yost, staff director, *Global* Future: Time to Act, Report to *the* president on *Global* Resources, *Environment* and *Population* (Washington, D. C.: U.S. Councd on Environmental Quality and Department of State, January 1981), p. 206.
[8]Arthur D. Little, Inc., op. cit., pp. IX-X.
[9]Ibid., p. xii.
[10]*The Global 2000* Report *to* the *President*, vol. 2, p. 454.

> This design is no institutional accident but is in conformity with the bureaucratic division of responsibility within the executive agencies [and within the committee structure of the U.S. Congress]. . . . Furthermore, in the absence of ongoing institutional incentives to address cross-sectional interactions, the present form of the government's global model is not likely to change significantly in the foreseeable future. [11]
>
> * * *
>
> Moreover, it would be naive not to recognize that projections and the procedures used to produce them have frequently been criticized by Congressional committees and others as subject to influences not purely analytical in origin. Each agency has its own responsibilities and interests, its own constituencies, and its own pet projects. Often, an agency finds it helpful to use advanced analytic techniques (and associated projections) as weapons in the adversary process of initiating, justifying, and defending its programs. As a result, there have been many occasions in which the elements (and associated projections) of the government's global model have been used in support of (or in opposition to) highly controversial programs, and the credibility of the projections has become a subject for debate. This has been especially true in recent times, as both the issues and the advanced analytic procedures used for examining the issues have become increasingly complex and, in a sense, incomprehensible to many nonexperts.[12]

Another analysis of the Government's current foresight capability points to these and similar institutional barriers. The following list of major obstacles presents 10 frequently cited reasons for the Government's failure to correct the perceived deficiencies in its existing foresight capability.[13]

1. There is little or no top-level support for foresight.
2. The "best talent" has never worked on broad, long-term issues.
3. Bureaucratic rigidity, compartmentalization, and specialization have frustrated attempts to promote cooperation among departments and to take a broad, long-term view.
4. Time pressures restrict vision to the short run.

[11]Ibid., vol. 2, p. 461 and footnote.
[12]Ibid., vol. 2, pp. 478-480.
[13]John M. Richardson, Jr., "Towards Effective Foresight in the United States Government" (prepared for the U.S. Department of State, June 1979), pp. 13-18.

5. By the time models or forecasts are developed, policy-level officials have either moved on or lost interest.
6. Policy-level officials lack the knowledge and experience to properly use models.
7. The products of modelers' efforts are incomprehensible or irrelevant [to practical policy issues], or both.
8. There is poor communication among those who contract for models and" forecasts, those who develop them, and those who are supposed to use them.
9. Congress doesn't care about the long-term future.
10. The public doesn't care about the long-term future.

CHAPTER 5

Priorities and Strategies for Improving **U.S.** Government Foresight

Contents

CHAPTER 5

Priorities and Strategies for Improving U.S. Government Foresight

Introduction

Numerous proposals for improving Government foresight have been put forward, both in the past and in response to the Global 2000 Report. [1] Some have been modest and limited, others sweeping; some would require major legislation from Congress, while others could be encouraged through oversight or carried out through executive order or agency initiative. The following discussion presents the most frequent and representative proposals, which generally reflect four fundamental priorities:

- correct the existing deficiencies in Government models, as identified by Global 2000 and other assessments;
- coordinate the Government's current predictive capability and activities;
- support technical improvements in the current capability and advance the state of the art; and
- link the Government's foresight capability with its policymaking and management activities.

These priorities and the various strategies for carrying them out do not represent "options" in the normal sense of the term. They are complementary and mutually reinforcing parts of a larger, integrated effort to make the Government's foresight capabilities more reliable, more coordinated, and more useful to both analysts and policymakers.

[1] See especially Dennis L. Little, et al., Long-Range *Planning* (Washington, D. C.: U.S. Library of Congress Congressional Research Service, 1976), prepared for the Subcommittee on the Environment and the Atmosphere of the House Committee on Science and Technology, pp. 384-390; John M. Richardson, Jr., "Towards Effective Foresight in the United States Government" (prepared for the U.S. Department of State, June 1979), pp. 5-6 and app. C; Arthur D. Little, Inc., *Long-Range Forecasting Models of Population, Natural* Resources, and *the Environment Their Use in* Foreign *Policy Assessments at the National Level* (prepared for the U.S. Department of State, Nov. 1979), pp. II.2-3; and *Global Future* Tune *to Act*

ACTION 1. —Correct the Existing Deficiencies Identified by Global 2000 and Other Assessments

Global 2000's authors, reviewers, and critics have identified numerous deficiencies in each of its component submodels, many of which are noted in chapter 2 and the appendixes to this report. The followup report by the interagency Task Group on Data and Modeling Capability identified the correction of these existing deficiencies as the first priority in improving the Government's ability to analyze and address global problems. [2] This action could be taken as a matter of course by individual agencies, many of which are already planning or carrying out evaluations and modifications of their present capabilities. However, such actions might be given higher priority, higher level attention, and greater coherence by the agencies if they were encouraged by a presidential directive and/or congressional oversight.

The Department of Energy's (DOE) Energy Information Agency has institutionalized this evaluative function in its Office of Energy and Information Validation, which might provide a model for other agencies. Another possible strategy for carrying out this priority would be the creation of high-level advisory committees within each of the relevant agencies. The functions of these agency advisory committees might include the following:

[2] "Report of the Global 2000 Task Group on Data and Modeling Capability," prepared for the President's Task Force on Global Resources and Environment, Nov. 7, 1980.

- prepare an inventory of existing models and data bases, including the purposes for which they were originally developed and the uses to which they are currently put, with particular attention to their scope, complexity, and assumptions;
- identify existing deficiencies and evaluate any plans to modify existing models or obtain new models, preferably through independent assessment by outsiders;
- evaluate current and potential applications of models and projections by agency analysts, planners, and policy makers, with particular attention to the specific information needs of potential users;
- encourage expanded use of models and projections through educational and training programs for agency personnel;
- improve communication between those who use models and those who develop or maintain them, with particular attention to increasing the relevance and responsiveness of model outputs to the needs of potential users; and
- identify likely future problems and issues within the agency's area of responsibility and interest, with the goal of developing problem-oriented and policy-relevant models and data bases.

ACTION 2.—Coordinate the Government's Current Modeling Capabilities and Activities

While the creation of agency advisory committees might be a useful and necessary foundation for improving the Government's foresight capability, it fails to address the equally important problem of linking and coordinating these agency capabilities, which currently focus on relatively narrow, mission-oriented sectoral concerns. Problem-oriented models would most appropriately be developed by the agencies that would use them, but overall analysis and policymaking would require consistent, integrated forecasts that incorporate data and projections from several agencies. Global 2000 shows that it is in this area that current Government efforts have been most unsuccessful: the delays in completing the study itself were caused in part by problems involving computer compatibility and tape transfer.

The simplest strategy for carrying out this action would be a process of interagency negotiation and arbitration to bring about greater consistency and compatibility between the separate agencies' data bases, assumptions, and projections. Ultimately, however, the effectiveness of such a process might require the creation of an interagency task force to provide a focal point and to resolve conflicts. The coordinating functions of such a task force might include the following:

- prepare an inventory of models and data bases currently maintained by individual agencies (including their respective strengths and weaknesses), and identify any areas of compatibility, overlap, or redundancy;
- identify gaps, sources of inconsistency, and points of conflict among existing agency capabilities and suggest possible solutions;
- promote greater understanding,. communication, and technical cooperation among agencies (simply getting the Government's modelers together was one of the Global 2000 study's major accomplishments);
- review and coordinate agency plans to modify or obtain new models or data bases, in order to prevent redundancy, ensure greater compatibility, and identify software or hardware needs;
- develop consistent procedures and protocols for data collection, standards of reliability, and validation, as well as for model documentation and validation;
- establish a central clearinghouse to provide information on the location of models and data bases and to permit easier access. exchange, and integration of data, assumptions, and projections;

- identify key future problems and issues, designate lead agencies to gather information and monitor trends in each area, and ensure the publication of timely projections; and
- link existing models, such as the World Integrated Model (WIM) maintained by the Joint Chiefs of Staff and other agencies, the Grain-Oilseed-Livestock model maintained by the Department of Agriculture, and the IEES/LEAP models maintained by DOE.

ACTION 3.—Support Technical Improvements in the Current Capability and Advance the State of the Art

Technical coordination among agencies and between the executive and legislative branches would eventually require some form of third-party mediation. Creation of an institutional mechanism for this purpose would also present an opportunity for carrying out research and development aimed at technical improvements in existing agency capabilities, the Government's capability as a whole, and the state of the art in global modeling generally. To carry out these functions, however, this institutional mechanism would have to be insulated from the day-to-day concerns of the line agencies and, thus, able to take a long-term view and incorporate broader and more diverse perspectives. Because its mission would be only indirectly linked to policy-related concerns, however, it would seem that such an organization should be created only in conjunction with other initiatives that are directly relevant to policy development and coordination (see action 4). Technical improvements are nevertheless a necessary prelude to policy applications,

Several strategies have been suggested for carrying out this priority. In the short term, an ad hoc commission or research advisory panel might be appointed to identify key technical problems and establish research priorities. To be effective, however, such an effort would have to be both open and ongoing. A frequently encountered proposal for the long term is the creation of a "hybrid" or "quasi-public" institute devoted to long-range analysis, global modeling, and futures research. The primary goal of such an institute would be to encourage private-sector understanding of, support for, and participation in Government foresight activities. Specific functions might include the following:

- solicit the thoughts and enlist the creative talents of the private sector, particularly the business and educational communities, to "cross-fertilize" Government ideas and initiatives;
- support research by nongovernmental organizations to create and/or improve global models and other analytic tools, especially those based on paradigms other than economics;
- encourage impartial, third-party validation and assessment of existing or proposed Government models;
- establish a "global modeling forum, " patterned on the Energy Modeling Forum, at which modelers could exchange ideas and critique one another's work;
- assess work done outside the Government or outside the United States and, where appropriate, suggest its incorporation into the Government's capability;
- support data-gathering efforts and the development of needed data-gathering technologies and systems; and
- establish and maintain communication with similar organizations in other countries through such organizations as the International Institute of Applied Systems Analysis.

ACTION 4.—Link the Government's Foresight Capability With Its Policymaking and Management Activities

The above-described institute, although it could help to broaden the dialog on global problems and advance the state of the art in global modeling, could not by itself ensure that these concerns would be translated into coordinated Federal policy. If the U.S. Government is at present giving insufficient attention to long-range global problems, it could be in part because no single agency has the mandate or the ability to look at these problems on an integrated, ongoing basis. A final priority, therefore, might be to create an institutional focus that could coordinate the various elements of the Government's foresight capability and ensure that long-range global concerns and national priorities are routinely taken into consideration in the formulation, selection, and implementation of U.S. policy at all levels.

In Congress, this would require continuing efforts to ensure that legislative proposals are evaluated in terms of their long-term global impacts and implications. One rationale for such evaluation might be provided by House Rule X, which directs in part that each standing committee (other than Budget and Appropriations):

> , . . shall review and study any conditions or circumstances which may indicate the necessity or desirability of enacting new legislation within the jurisdiction of that committee . . . and shall on a continuing basis undertake futures research and forecasting on matters within the jurisdiction of that committee (2(b)(l)).

The long-range analytic capabilities of the legislative support agencies might also be coordinated and brought to bear on such issues. In addition, Congress might also encourage appropriate initiatives in the executive branch through oversight hearings, personal appeals, or directed research. For example, several committees have already held or plan to hold hearings on long-range demographic issues, Global 2000, and Government foresight. In addition, Sen. Charles McC. Mathias has written a letter to the President, cosigned by 84 other Members, strongly urging that he give the *Global Future: Time to Act* report his thoughtful consideration and that he "put into motion the machinery that will translate these recommendations into action. "[3] Another example is the request by the Technology Assessment Board for this OTA study.

Proposals for creating an institutional focus for long-range global policymaking in the executive branch usually suggest that–to ensure support from and access to high-level decisionmakers—it should be located in the Executive Office of the President (EOP). The current administration has

[3]Sen. Charles McC. Mathias, letter to the President, June 22, 1981. This letter, initiated by Senator Mathias and sponsored by Senator Dodd and Representatives Udall, Conte, and Schneider, was signed by the following Members of the House and Senate:

Sen. Charles McC. Mathias, Jr.	Rep. Howard Wolpe
Sen. Christopher J. Dodd	Rep. Jerry M. Patterson
Rep. Morris K. Udall	Rep. Harold C. Hollenbeck
Rep. Silvio O. Conte	Rep. Stephen J. Solarz
Rep. Claudine C. Schneider	Rep. Mike Lowry
Sen. Charles H. Percy	Rep. M. Caldwell Butler
Sen. Mark O. Hatfield	Rep. Barbara A. Mikulski
Sen. Alan Cranston	Rep. Bill Frenzel
Sen. Dale Bumpers	Rep. Fortney H. Stark
Sen. Claiborne Pell	Rep. Thomas A. Daschle
Sen. Lowell Weicker	Rep. Lawrence J. DeNardis
Sen. Carl Levin	Rep. Frank Horton
Sen. George Mitchell	Rep. Leon E. Panetta
Sen. Robert Stafford	Rep. Claude Pepper
Sen. Paul Tsongas	Rep. Bruce F. Vento
Sen. Harrison Williams	Rep. Cooper Evans
Sen. Paul S. Sarbanes	Rep. Les AuCoin
Sen. Thomas F. Eagleton	Rep. Berkeley Bedell
Sen. Edward M. Kennedy	Rep. John LaFalce
Sen. Spark M. Matsunaga	Rep. James M. Jeffords
Sen. John C. Danforth	Rep. Vic Fazio
Sen. Daniel K. Inouye	Rep. Richard L. Ottinger
Sen. William C. Cohen	Rep. Donald Pease
Rep. Barney Frank	Rep. George E. Brown, Jr.
Rep. James H. Scheuer	Rep. Thomas J. Tauke
Rep. Timothy E. Wirth	Rep. Jonathan B. Bingham
Rep. Sam Gejdenson	Rep. Matthew F. McHugh
Rep. Richard A. Gephardt	Rep. Patricia Schroeder
Rep. John Conyers, Jr.	Rep. James Weaver
Rep. Paul McCloskey	Rep. Bob Edgar
Sen. Don Riegle	Rep. William R. Ratchford
Sen. John H. Chaffee	Rep. Ron Wyden
Sen. Max Baucus	Rep. Norman Y. Mineta
Sen. Walter D. Huddleston	Rep. Nicholas Mavroules
Sen. Dan Quayle	Rep. Dante B. Fascell
Rep. Millicent Fenwick	Rep. William Lehman
Rep. Gerry E. Studds	Rep. Philip R. Sharp
Rep. Wyche Fowler, Jr.	Rep. James L. Oberstar
Rep. Albert Gore, Jr.	Rep. Charles E. Schumer
Rep. Anthony C. Beilenson	Rep. Edward J. Markey
Rep. Baltasar Corrada	Rep. Shirley Chisholm
Rep. Anthony Toby Moffett	Rep. George W. Crockett, Jr.
Rep. Edwin B. Forsythe	

apparently taken a step in this direction by creating a new "national indicator system" directed by a special assistant to the President. He describes the project as "a system for providing social and demographic information to the policy people in a systematic and regular way, in advance of policy debates," in order to give high-level policy makers "a view of [the] changing world" and a sense of how "everything has its cross-impacts on everything else in society."[4] The system, which will lead to twice-monthly briefings for the President, Vice-President, Cabinet, and senior EOP staff, will focus primarily on national trends but will also examine international trends if there is an obvious connection or a special request from the "long-range policy group" that previews the briefings.

Other proposals for structuring and housing an EOP foresight capability have included the following options:

- Create a new office in EOP devoted exclusively to long-range global issues.—Such an entity would give the issues greatest emphasis, ensure access to the President, avoid competing responsibilities, and facilitate coordination of agency capabilities and activities.
- Assign responsibility for these issues to an existing EOP office.—This would avoid the need to create a new EOP unit. Several existing offices (e.g., the Office of Management and Budget, National Security Council, or Council on Environmental Quality (CEQ)) have analogous or complementary missions and expertise, and CEQ has already begun planning a followup to the Global 2000 study. Additional staff and resources would have to be made available, and there is a possibility that long-range global issues might not receive full attention because of the unit's existing functions and responsibilities.
- Create an interagency coordinating committee on long-range global issues.—Such a committee might be chaired by the Vice President (in conjunction with his current duties as chairman of the Crisis Management Team) or by the head of an existing EOP unit, but even with a staff of its own it would probably be less efficient and less effective than a dedicated office.
- Assign responsibility for policy develop" ment on long-range global issues to a Special Assistant to the President.—Such an individual, with the help of a small staff, could have access to the President and could ensure a somewhat better degree of interagency coordination, but this office would have to depend, in turn, on modeling and analytic expertise from other sources.

[4] Richard Flea], Special Assistant to the President and director of planning and evaluation; quoted by Philip J. Hilts, "White House Uses Social Sciences But Cuts Funding for Research," *Washington Post*, June 29, 1981, p. A8.

The functions and objectives that have been suggested for this new EOP office include the initiation, supervision, and coordination of all of the functions outlined for the preceding priorities, plus the following:

- ensure that the President and other top-level decisionmakers are presented with the best possible analyses and broadest possible range of policy options on long-range global issues;
- use global models (in combination with other analytic techniques) to determine the effect of various agency goals and budget items on long-range global trends and strategic interests;
- encourage an open and vigorous national dialogue on long-range global problems and issues, with the goal of developing a clear definition of U.S. national goals and strategic interests in these areas;
- prepare a "policy statement on the future," to be presented by the President, as a means of focusing attention and forcing action on long-range global issues;
- issue periodic reports, similar to an executive agency's annual report to Congress, on major global issues and, at longer intervals, conduct comprehensive, integrated studies of long-range global trends and problems;
- issue periodic reports on the state of the art in global modeling and the state of the Government's foresight capability; and
- in conjunction with the Department of State, encourage similar assessments of long-range issues by foreign governments and cooperate in the data-gathering and analytic activities of the various international organizations.

Appendixes

APPENDIX A

Population Projections

Introduction

Population projections play a key role in any assessment of future world conditions, since the size of the population determines the number of consumers of goods and services and the number of people available to produce those goods and services. The rate and distribution of population growth will also determine the short-term strains that are put on the world's socioeconomic system, just as the ultimate size of population will determine the long-term strains that are put on the planet's physical and biological systems. Three of the global models–World 3, World Integrated Model (WIM), and Latin American World Model (LAWM) —try to describe the general long-term behavior of all components of the global system, including population. In these models, the determinants of population change—fertility and life expectancy—are linked to other sectors through feedback loops that simulate the effect of changing physical and socioeconomic conditions on the rate of population growth. The other models try to provide a detailed, short-term prediction of world conditions; in these models the future size of the population is projected in a more straightforward way, unrelated to the projection of other conditions.

These differences in purpose and technique, combined with differences in time horizon and the uncertainties surrounding the present size and future behavior of the world's population, lead to variations in the projections themselves and in their relative reliability. The projections are also influenced by policy assumptions and by the models' degree and pattern of geographical regionalization. All of these factors affect the usefulness of the models and projects for the policymaker.

Purposes, Structures, and Projections

World 3

This highly aggregated global model was designed to display the long-term interactions among major world systems—population, nonrenewable resources, capital, agriculture, and pollution—in order to investigate the consequences of five major trends at the global level: accelerating industrialization, rapid population growth, widespread malnutrition, depletion of nonrenewable resources, and environmental deterioration. In order to examine the long-term effects of these trends, the model *was* designed to simulate interactions over a 200-year period, from 1900 to 2100. The system dynamics modeling technique is particularly useful for simulating two important kinds of system behavior—feedback and delays–and is thus a powerful tool for understanding complex system behavior. This makes it a suitable approach for exploring the general shape of long-term global system behavior, but it is generally less useful than other techniques for producing accurate short-term forecasts of individual variables.

The population sector of World 3 is highly aggregated: it has only one geographic region and only four different age groupings: O to 14, 15 to 44, 45 to 64, and over 64. Global population is determined solely by the effects of changes in birth rates and death rates, but the determination of these rates depends heavily on interaction with the rest of the model. The death rate is calculated from average world life expectancy, which in turn is determined by four influences that the authors, based on historical evidence and expert judgment, postulate in the following relationships:

- Life expectancy 'increases with increasing food availability, reaching a maximum when food per capita is about four times the present world average.
- Life expectancy increases with increasing health services per capita, although with about a 20-year delay.
- Life expectancy initially increases with crowding because of increased industrialization and urban services, but beyond a certain level crowding has a negative influence on life expectancy due to the effect of local pollution and stress-related diseases.
- Life expectancy decreases as the amount of persistent pollution increases.

These relationships are intended to capture the general direction and magnitude of the four influences on life expectancy. Although exact equations must be entered into the model, these equations are not meant to be rigorous quantifications of the actual relationships.

The birth rate is calculated from the fertility rate, which in turn is influenced by two factors: desired fertility, and fertility-control effectiveness. Fertility-control effectiveness is expressed *as a* function of level of development, as measured by industrial output per capita, and reaches 100 percent at a level of development three times higher than the current average world level. Desired family size is assumed to be affected by two further influences-the social norm and the individual response

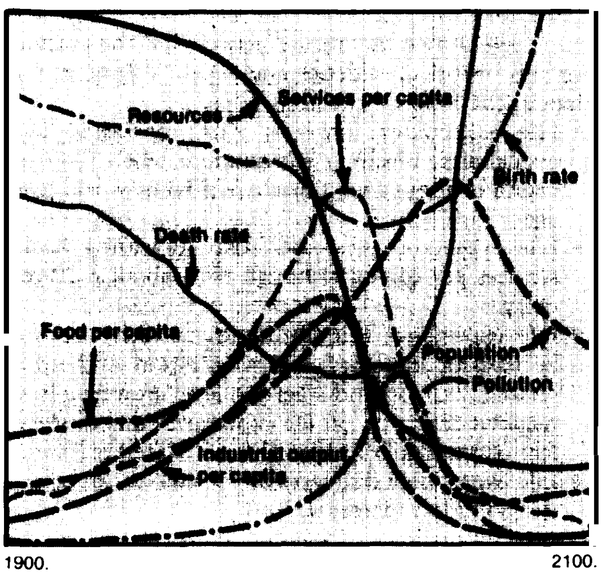
[1]The following material is based on an OTA working paper prepared by J. Stover of the Futures Group, Glastonbury, Corm. For further Information on this subject, see OTA's assessment, *World Population and Fertility-Planning* Technologies The Next 20 Years, OTA-HR-157, February 1982.

to the social norm—in such a way that desired family size ranges from a high of 5 children when income is low to a low of 1.5 children when income is high. As with life expectancy, however, the specification of these relationships is based on expert judgments aided by the small amount of available historical evidence.

The entire World 3 model was calibrated by simulating the period from 1900 to 1970, during which period the model correctly represents the broad dynamics of world population.

In the standard run of the World 3 model, world population increases to about 6 billion by 2000 and reaches a maximum level of about 7 billion by 2025, but then declines rapidly to only 4 billion by 2100 (see fig. A-l). This decline occurs because resource depletion causes an increasing fraction of capital to be used in extracting raw materials, thereby reducing the amount available for other investments, especially agricultural production. As investment in agriculture lags, food per capita begins to decline, causing a higher death rate, a decline in life expectancy, and ultimately a decline in population. This model run is meant to represent the most likely mode of system behavior if there is no change in past trends and policies, and the authors argue that it demonstrates the need for action to ensure that such a result does not occur.

Figure A-1.—World 3 Standard Run



The "standard" world model run assumes no major change in the physical, economic, or social relationships that have historically governed the development of the world system. All variables plotted here follow historical values from 1900 to 1970. Food, industrial output, and population grow exponentially until the rapidly diminishing resource base forces a slowdown in industrial growth. Because of natural delays in the system, both population and pollution continue to increase for some time after the peak of industrialization. Population growth is finally halted by a rise in the death rate due to decreased food and medical services.

SOURCE: *Limits to Growth.*

In a series of sensitivity and policy tests, the authors show that neither increased resources nor improved technologies have any significant effect on this basic behavior mode: population invariably peaks before 2050 and declines thereafter, although the maximum population varies from 7 billion to 9 billion and the population in 2100 varies from 3 billion to 5 billion. The reasons for the collapse do change, however: for example, when the resource limits to growth are removed, increases in pollution become the factor that eventually causes the death rate to increase.

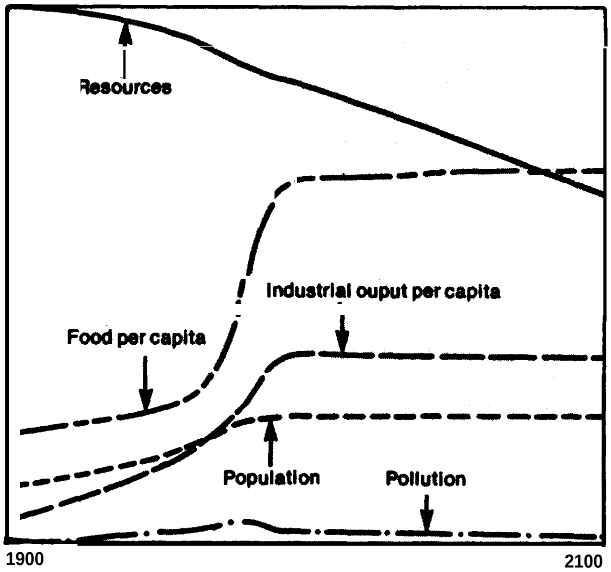
Only two scenarios were able to avoid the basic pattern of overshoot and collapse. In the first, based on the highly unrealistic condition of removing all the physical limits to growth, population continued to grow and reaches about 14 billion by 2100. The second is the "global equilibrium" scenario, based on an integrated set of policies designed to bring about a gradual transition to a stable, nongrowth world (fig. A-2). These policy changes, all of which are implemented beginning in 1975, include the availability of "perfectly effective" birth control and a worldwide reduction of desired family size to 2 children. Under these conditions, the population grows to only 5 billion by 2000 and stabilizes at around 6 billion by 2050. If the needed policy changes are delayed until 2000, however, the equilibrium state is not sustainable (fig. A-3).

The usefulness of this model to policy makers lies mainly in pointing out the potential dangers ahead, the costs of delaying action, and the need for considering the whole system when thinking about one aspect of the problem. However, since the model does not contain adequate policy levers (i.e., policymakers cannot directly control the variables in the model), its usefulness for policy testing and evaluation is limited.

World Integrated Model (WIM)

This global model, the first of several to be built in response to what many saw as the inadequacies of World 3, differs from the latter in one major aspect—disaggregation. WIM represents a world composed of many different subsystems that interact with one another hierarchically on five different planes or strata: individual, group, demographic-economic, technological, and environmental. It also divides the world into 10 or more geographic regions; each region is a complete model in itself, but interacts with the other regions through international trade. The model is not an explicit system

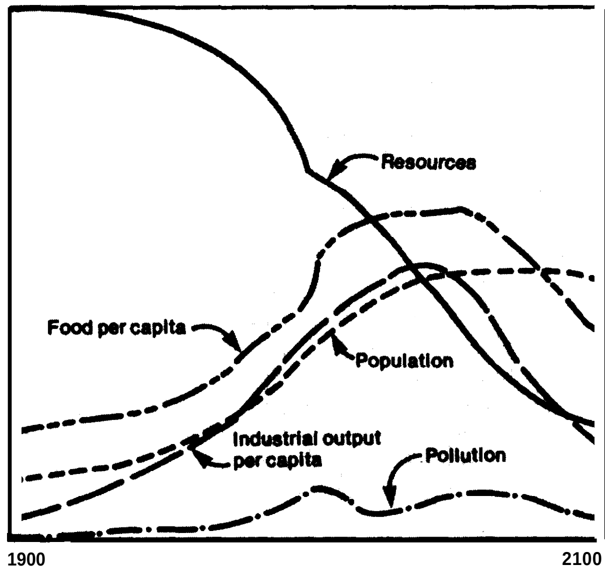
Figure A-2.—World 3 Equilibrium Run



Technological policies and growth-regulating policies produce an equilibrium state sustainable far into the future. Technological policies include resource recycling, pollution control devices, increased lifetime of all forms of capital, and methods to restore eroded and infertile soil. Value changes include increased emphasis on food and services rather than on industrial production. Births are set equal to deaths and industrial capital investment equal to capital depreciation. Equilibrium value of industrial output per capita is three times the 1970 world average.

SOURCE: Limits to *Growth.*

Figure A-3.—World 3 Run With Stabilizing Policies Introduced in the Year 2000



If all the policies instituted in 1975 in the previous figure are delayed until the year 2000, the equilibrium state is no longer sustainable. Population and industrial capital reach levels high enough to create food and resource shortages before the year 2100.

SOURCE: Limits to Growth.

dynamics model, but it does incorporate some of the feedback relationships and delays that are contained in World 3, as well as many new ones.

The population sector of each region divides the population into 85 l-year age cohorts. Fertility is determined by the level of socioeconomic development in each region, including both the reduction in desired family size and the increased effectiveness of contraceptive use. Increasing levels of education also lead to declining fertility.

Mortality is also linked to the rest of the model. Life expectancy increases with increasing level of development and (in some versions of the model) it is also affected by food availability: the model calculates the amount of calories and protein available in each region, and when these amounts fall below sufficient levels, additional deaths due to starvation result. All of these relationships are judgmentally determined–as in World 3, they are meant to capture the general shape of the real-world relationships, without attempting to quantify them rigorously.

The standard run of the model shows the result of continuing historical patterns of development. In this run, however, the relationships between education, development, and fertility are replaced by the "optimistic though reasonable" assumption that successful population policies will cause fertility rates in all regions to drop to the replacement level (i.e., births equal deaths) within 35 years. The authors did this in order to "avoid biases that might be introduced by the predominance of population growth factors."[2] This standard run shows world population increasing from 4 billion in 1975 to about 6.4 billion by 2000 and stabilizing at about 6.8 billion by 2015.

In other runs the authors have examined the effects on world population of delays in starting a worldwide policy to achieve replacement fertility rates. Assuming that it takes 35 years from the start of such an effort until replacement level fertility is reached, they found that world population would stabilize at about 7 billion if the effort is started in 1975, 10 billion if it is started in 1985, and 12 billion if it is started in 1995.

Because of the differences in regional detail, the conclusions of the WIM study are different from those of

[2] M. D. Mesarovic and E. Pestel, *Mankind at the Turning Point* (New York: Dutton, 1974), p. 57.

World 3. The authors conclude that worldwide collapse is not likely to result even if past trends continue, but that catastrophes could well occur at the regional level well before 2050. These regional collapses, occurring at different times and for different reasons, will nevertheless profoundly affect the entire global system. The solution to this problem lies not in stopping all growth but rather in achieving what the authors call "organic growth' '-i.e., different kinds of growth in different regions, such as continued industrial growth in the LDCs but service-oriented growth in the developed countries. Without early action to ensure a transition to this kind of balanced, differentiated growth, the authors say that regional and finally global disaster is inevitable.

The model was designed to be employed by policymakers. Extensive work has gone into making the model interactive so that policy makers can experiment with it and, thereby, increase their understanding of the future effects of current policy decisions. Since the original model is not disaggregated to the country level, policymakers cannot see the effect of specific policies that they might implement in their own countries. However, subregional and country models based on the same concepts have been developed by former members of the modeling team in response to the needs of specific clients.

Latin American World Model (LAWM)

This model was also constructed in response to limitations seen in the World 3 model, and in particular to its disturbing implications for the developing world, If economic growth must stop soon in order to avert world collapse, what hope do the poor countries have of ever alleviating their poverty? The Latin American authors of this study concluded that the proper question to ask is: "What changes in the structure of the present socioeconomic system would be required in order to bring about a better life for all?"

Since the model attempts to answer a different question, its modeling technique is also different. LAWM is based on optimization techniques, and the model is structured in such a way as to determine the allocation of labor and capital that will ultimately maximize life expectancy—its measure of the satisfaction of basic human needs. The model divides the world into four regions—the developed countries, Latin America, Africa, and Asia—each of which functions more or less independently. The model does contain some physical constraints, but its structure reflects a general underlying assumption that physical limits to growth will not be as important as social and political limits. As a result, its projections do not reflect how the world will be, but rather how it could be if the indicated allocation policies were followed.

The population sector of LAWM, which is designed to identify the social and economic factors that influence population growth and life expectancy, is both more detailed and more complicated than those of World 3 and WIM. The complex web of variables and influences (shown in fig. A-4) can, however, be reduced to a single, fairly straightforward hypothesis: "The only truly adequate way of controlling population growth is by improving basic living conditions."[3] Thus, the allocation of capital and labor to any of the basic needs sectors—food, education, housing, and other consumer goods and services—will result in lower birth rates and/or higher life expectancy. These influences are in fact compounded, since lower birth rates lead to higher life expectancy, which in turn leads to a further decrease in birth rates.

Education and agriculture seem to have been given particular weight in LAWM, but all of the relations were estimated through descriptive analysis, using scattered data and rather esoteric mathematical techniques, and they should not be confused with causal relationships, although the formulation of the model implicitly assumes them to be causal.[4] The correlations between estimated and actual birth rate and life expectancy for the test period (1960-70) are very high (+0.90 and +0.95, respectively), but this technique gives no indication of whether or not the postulated functions are correct. If demographic change in the real world follows different rules, this optimization procedure will not generate reliable projections.

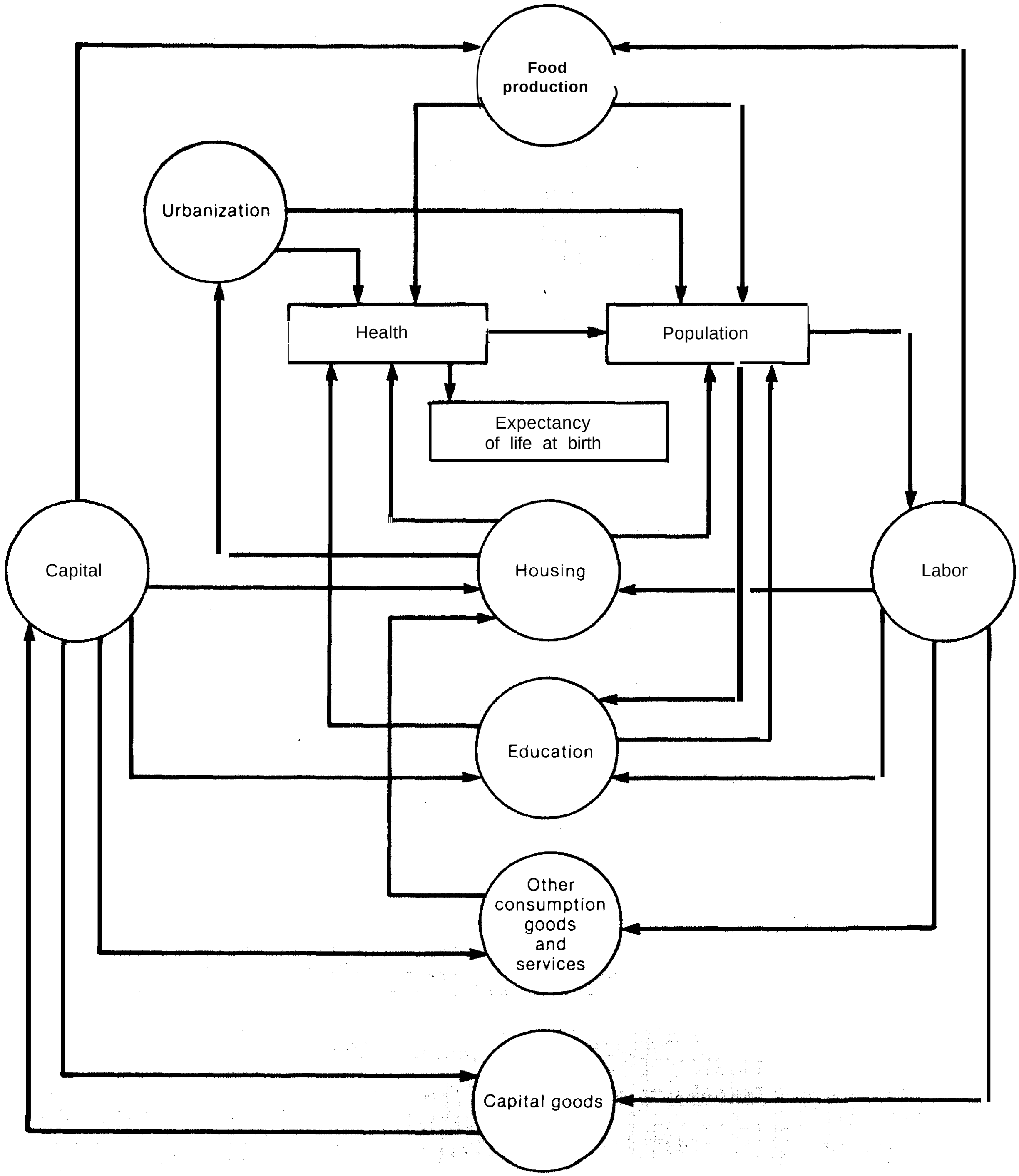
The results of the LAWM standard run are mildly optimistic for all regions except Asia, where the only basic need that is satisfied is education. By 2010 all available land in Asia is being cultivated, which means that the growth of food production is unable to keep up with population growth; although progress continues in housing and income, food availability per capita falls to dangerous levels, and the delay in achieving basic needs causes a delay in reducing population growth. The population projections show a total world population of 6.4 billion by 2000, 1,2 billion in the developed world and 5.2 billion in the developing world. By 2040 the world population reaches 11 billion and is still growing at 1.1 percent per year, due largely to the 1.4 percent growth rate in Asia.

The usefulness of this model for policymakers lacks mainly in its ability to display the effects of adopting a particular broad strategy—that of allocating labor and capital in a manner that corresponds statistically to

[3] A. O. Herrera, et al., *Catastrophe or New Society? A Latin American World Model* (Ottawa: International Development Research Center, 1976), p. 8.

[4] See J. Robinson, "The Latin American World Model," in *The Global 2000 Report to the President* (Washington, D. C.: U.S. Council on Environmental Quality and Department of State, 1980), vol. 2, pp. 638 and 641; and D. H. Meadows, J. Richardson, and G. Bruckmann (eds.), *Groping in the Dark: The First Decade of Global Modeling* (New York: Wiley, forthcoming), p. 97.

Figure A-4.— Basic Structure of LAWM



SOURCE: Gracielle Chichilnisky, "Latin American World Model: Theoretical Structure and Economic Sector," in *Proceedings of the Second IIASA Symposium on Global Modeling*, Gerhart Bruckmann (ed.) (Laxenburg, Austria: International Institute for Applied Systems Analysis, 1976), p. 126.

maximized life expectancy. LAWM does not contain policy levers that might be exercised by an individual planner, but the model has nevertheless contributed to the debate on broad strategy by describing an alternative to the present world order.

The United Nations Input-Output World Model (UNIOWM)

The particular goal of this study was to assess the impact of various economic issues and policies on the International Development Strategy for the Second United Nations Development Decade. Specifically, the model was to address the question of whether the existing policies and development targets were consistent with the availability of world resources. Because it uses an input-output approach, the model can be used either to investigate the rates of economic growth achievable given certain constraints (resources, balance of payments, etc.) or to investigate investment and consumption levels that would be consistent with given rates of economic growth.

Unlike the other global models, however, population growth is entirely exogenous in UNIOWM. Although the size and composition of the population affect the rest of the model, there is no feedback from the rest of the model to population. In fact, the model has no population sector as such: it simply uses the population projections prepared by the United Nations Population Division for the 1973 assessment of world population, (This assessment was updated for all countries in 1978, and the discussion below deals with the more recent figures.) These projections, include four variants-high, medium, low, and constant-the constant case is merely a reference projection assuming no change in a country's fertility rate. The medium variant is designed to represent the most likely future demographic trends, based on past and present demographic trends, expected social and economic progress, ongoing government policies, and prevailing public attitudes toward population issues. The high and low variants are intended to reflect plausible variations on these factors.

The fertiltiy assumptions underlying the projections are based on past and present fertility trends in each country, adjusted judgmentally by experts in the U.N. regional population offices around the world and reviewed in the Population Division at U.N. headquarters in New York. These judgments were guided by three general principals:[5]

- Fertility rates will decline as economic and social development takes place.
- Existing or anticipated government policies and programs, as well as nongovernmental activities aimed at such a goal, will expedite the process of fertility decline.
- Once initiated, fertility decline will begin slowly, gain momentum, and then slow down again. For those countries with fertility levels near or below the replacement level, it is assumed that fertility will begin to converge on replacement level before the end of this century.

Judgmental estimates of life expectancy were also prepared for each country, following the general rule that life expectancy would increase by 2.5 years every 5 years until it reaches 55, after which the rate of increase would be less. (For some countries where development has been slow, this rule was changed to allow slower increases.) The projections also take into account assumptions about internal migration (urbanization) in each country.

In the projections prepared by the U.N. in 1978, the population of the world increases from 4 billion in 1975 to 5.9 billion, 6.2 billion, and 6.5 billion by 2000 for the low, medium, and high variants, respectively. Most of this growth occurs in the developing world: the population of the more developed countries increases by only 13 to 21 percent from 1975 to 2000, while the increase for the less developed world is 57 percent in the low variant to 77 percent in the high projections.

The most rapid rate of growth is in Africa, where population increases by 114 percent from 1975 to 2000, and in Central America and the Caribbean, where it increases by 115 percent. China's population is projected to increase by 26 to 37 percent; this is only half the average rate for all developing countries, although it means an additional 235 million to 335 million people by 2000. India will add even more people to its population, an additional 360 million to 480 million people.

These population projections are used by UNIOWM to explore the consequences of the goals adopted for the Second Development Decade. This model has great utility in displaying the results that would occur if these goals were achieved, and as such it has been useful to those planning the broad strategy of the development decade. Unfortunately, the goals and prescriptions of the development decade do not always have a significant influence on actions taken by individual countries.

Global 2000

This study, conducted by an interagency task force that drew on the expertise and models of the entire U.S. Government, is one of the most comprehensive models in terms of the number of variables it examines. However, the separate submodels comprising "the Government's global model" are not linked to each other, and as a result there is no feedback or interaction between sectors. As a result, the population figures do not

[5] United Nations, *World Population Trends and Prospects by Country 1950-2000 Summary Report of the 1978 Assessment* (New York: United Nations, 1979), p. 2.

reflect the model's pessimistic projections of GNP or food production.

The population projections that were used in most sectors of Global 2000 were prepared by the U.S. Bureau of the Census in 1977. Like the U.N. projections, they are presented with high, medium, and low variants for all regions and selected countries. Underlying all three variants are the assumptions that: 1) fertility will decline more or less continuously throughout the period; 2) all countries will have adopted some kind of family planning program by 2000; and 3) the effectiveness and coverage of such programs will increase. The different fertility rates used in the high, medium, and low variants are based on the judgment of experts and reflect the range of uncertainty about current fertility, future development patterns, and government family planning policies. Specific individual judgments are not reported, however.

The final Census Bureau projections extend to the year 2000 and are substantially the same as the U.N. projections: global population grows to 5.8 billion in the low variant, 6.2 billion in the medium variant, and 6.5 billion in the high variant. The population of the developed regions grows to between 1.3 billion and 1.4 billion by 2000, while the less developed regions grow to between 4.5 billion and 5.1 billion.

An alternative set of projections, prepared by the Community and Family Study Center (CFSC) at the University of Chicago under the sponsorship of the Agency for International Development (AID), is also presented in the *Global 2000 Report* but is not used in other sectors. These projections, too, include high, medium, and low variants, but in this case the projected fertility rates are based on a model of fertility decline that relates the rate of decline to the current level of fertility and the strength of family planning efforts within each country. The variants therefore reflect more explicit assumptions about family planning efforts: the high variant assumes that each country maintains its present level of family planning; the medium variant assumes that nations will implement strong family-planning programs by 2000; and the low variant assumes that strong programs will be in place by 1995 and that the effectiveness of these efforts will increase. These assumptions were developed through regression analysis of data for 1968-75, which showed that the strength of family-planning efforts had as much effect on fertility rates as all the measures of socioeconomic development combined.

Because they assume policy changes that would increase the efficacy of family-planning services, the CFSC projections are generally lower than those of the U.N. and Census Bureau: world population reaches 5.8 billion, 5.9 billion, and 6.0 billion by 2000 in the low, medium, and high variants, with the developed regions growing to between 1.2 billion and 1.3 billion and the less developed regions to between 4.5 billion and 4.7 billion. These projections have also been extended to 2050, at which date they show a global population of between 7.8 billion and 8.1 billion people.

The Census Bureau projections, those prepared by CFSC for AID, and all other "stand-alone" projections are useful to the policy maker mainly because they provide an input describing the population conditions under which policy must operate. Such projections are of little direct use to policy makers, but they often become key elements in the analyses that are prepared during the development of policy options.

Other Population Projections

Projections of world population have also been prepared, without the use of a global model, by the World Bank and Harvard University. The World Bank projections, last revised in 1979, were prepared by estimating, for each country, the year in which fertility will reach replacement level.[6] (As defined by the World Bank, "replacement-level fertility" refers to the level at which the number of births equals the number of deaths at the prevailing level of mortality. For countries with high mortality rates the replacement fertility level is considerably higher than 2 children per couple; as mortality declines, fertility must also continue to decline. Thus, a stationary population might not be achieved for more than 100 years after the achievement of replacement-level fertility.) The World Bank projections assume that fertility decline toward the replacement level had started by 1975 in all regions except Sub-Saharan Africa, where the decline was expected to start between 1980 and 1985. These projections show population increasing to 6.0 billion by 2000, with 1.3 billion in the developed world and 4.7 billion in the developing world; the population of the entire world becomes stationary around the year 2175 at a level of 9.8 billion.

In 1977, the Center for Population Studies at Harvard University prepared a single population projection for all countries and regions of the world to the year 2075.[7] In these projections, fertility is assumed to decline to replacement levels by 1990-95 for the developed countries and by 2000-05 for the developing countries; they show the population of the world increasing to 5,9 billion by 2000 and 8.4 billion by 2075.

[6] K. C. Zachariah and My Thi Vu, *Population Projections, 1975-2000 and Long-Term (Stationary Population)* (Washington, D. C.: World Bank, 1979).

[7] G. Littman and N. Keyfitz, *The Next Hundred Years* (Cambridge, Mass.: Harvard University, 1977).

Strengths and Weaknesses of Population Projection Techniques

Among the studies discussed here there are at least two different goals:

- to describe the long-term behavior of the global system; or
- to provide an accurate, short-term (25 years or less) picture of the world situation.

The long-term global modeling studies (World 3, WIM, LAWM) are clearly concerned with the first goal only. They examine the behavior of the entire global system over the next 50 to 125 years, but they make no attempt to provide accurate forecasts of world population (or any other variable) for 2000. All three studies take great pains to point out that accuracy of individual numbers is not a concern. The studies that limit themselves to projecting population only (World Bank, Harvard) are generally trying to satisfy both goals; they present country-by-country forecasts of population in 2000, but they also present longer views of population growth. The two modeling studies that limit themselves to 2000 (UNIOWM and Global 2000) are clearly interested primarily in the second goal.

These two different goals require the use of two fundamentally different modeling techniques. The first approach (long-term system behavior) considers population as only one of the many elements involved in the integrated behavior of the system: it affects the other sectors and, in turn, is affected by them. With this approach the most important aspects of the population sector are the effects of the rest of the model on population growth. The second technique (accurate short-term forecasts) considers population alone, without integrating it into the world system, It strives for accuracy by making separate projections of the individual countries, which are useful in themselves and can also be summed to produce a world total.

Long-Term Integrated Projections

The first technique has obvious advantages for projecting long-term system behavior. Population really is affected by the rest of the global model—by food production, pollution, and economic and social development—and it is essential to take these factors into account in projecting population growth over a long time period. The difficulty with this approach, however, is that the relationships between fertility, life expectancy, and other variables are not known precisely, nor is the historical evidence rich enough to allow these relationships to be estimated with any degree of confidence. In order to include the relationships in their model, therefore, the modelers are often forced to rely on rough estimates and informed guesses. The sensitivity of the model's behavior to these judgments can be tested, of course, but the reliance on judgment does make the model speculative.

Within this first general approach the models discussed here have adopted three variations. World 3 aggregates everything to the level of the world, with no geographical divisions. This was certainly appropriate for the preliminary versions of the model, which were meant to be simple, easily explained outlines of the eventual model. The large effort that went into constructing and documenting World 3 might have been better served if some regional disaggregation had been employed, but this would have at least doubled the amount of work involved in developing, testing, and documenting the model.

The development gap between the developed and less developed world is so large, however, that the two regions cannot properly be considered as one. WIM divides the world into 10 or more regions, and it therefore supplies a much more detailed representation of real-world behavior. In most of the initial WIM runs, however, the link between fertility and the rest of the model was broken and an optimistic fertility assumption imposed, although mortality rates did respond to the rest of the model.

LAWM takes the same general approach to the population sector as the other two models, with one major difference: the model is not designed to simulate actual world conditions, but rather to simulate what would take place if resources were allocated optimally in order to maximize life expectancy. Since this is not the way the world actually operates, LAWM's usefulness is in describing the world that would evolve, given a particular new mode of behavior, and not in describing what is likely to happen.

Short-Term Stand-Alone Projections

The second method of projecting population is used by each of the other studies. In this approach the population projections are linked to the rest of the world only insofar as the rest of the world is considered by the experts when they make their judgments about fertility and mortality decline. When the U.N. experts made their estimates, for example, they had in mind some view of the future world which influenced their judgments. Their worldview obviously excluded such disasters as nuclear war and massive famine, or their life expectancy assumptions would not have shown steady increases; but it is impossible to describe just what that worldview was. Indeed, since many different people were involved in this exercise, many different (and possibly conflicting) views of the world were used. It is impossible to say whether these worldviews were internally or mutually consistent, or to what extent any of them reflect the feedback effects between population and development. The most that can be said is that the experts generally assumed that the forces at work in the past would continue to operate, with the future largely growing out of a continuation of past trends.

Is this assumption of a "surprise-free" future reasonable? All of the global studies discussed here (including the long-term studies as well as Global 2000 and the UNIOWM) apparently consider this assumption reasonable in the short term. None of the studies show large-scale effects on population due to famine or resource shortages before 2000, although WIM shows regional starvation in Asia. In the longer term, however, the situation is different. The three long-term modeling studies show a high likelihood of significant changes beyond 2000: World 3 shows a collapse of population after 2030, WIM shows rapidly increasing deaths due to starvation in South Asia before 2025, and LAWM shows food availability in Asia dropping to starvation levels by 2040 in its standard run. Other studies not based on mathematical models, such as Herman Kahn's The Next 200 Years,[a] do not foresee such problems, but the assumption of a long-term continuation of past trends is certainly questionable. The likelihood of such a future actually developing can only be addressed through a comprehensive, integrated study of all factors affecting population growth.

[a]H. Kuhn and A. Wiener, *The Year 2000 A Framework for Speculation on the Next Thirty-Three Years* (New York: Morrow, 1967).

Factors Affecting the Reliability and Accuracy of Population Projections

Differences in purpose and time horizon also affect the reliability and accuracy of the resulting population projections. World 3, for example, attempts to describe the general behavior of the global system to the year 2100. The precision sufficient for such a model is quite different from that desired in the U.N. or Census Bureau population projections, which are used to predict the populations of individual countries in 2000.

Table A-1 shows the results of the studies that have made long-term population projections. There are two notable differences. Due to increasing death rates, population actually begins to decline in the World 3 model after 2025 and presumably would do so for Asia in WIM and LAWM if they had continued beyond 2060; the other projections all show steadily growing popula-

Table A-l.—Comparison of Long. Range Population Projections

Projection source	Projection	Results
World 3	**Standard run**	**Population increases to 7 billion by 2025 then decreases to 4 billion by 2100**
	Stationary world	**Population stabilizes at 6 billion by 2050**
World Integrated Model	**Standard run**	**Population stabilizes at just under 7 billion by 2015. Death rates due to starvation are high in Southeast Asia**
Latin American World Model	**Standard run**	**Population reaches 11 billion by 2040 and is still growing at 1.1 percent/yr. Death rates are rising rapidly in Asia**
	Second run—improved conditions in Asia	**Population reaches almost 11 billion by 2060 and is growing at less than 0.5 percent/yr.**
United Nations	**1978 population assessment**	**[a]Population reaches 8 to 12 billion by 2050 and stabilizes at 8 to 14 billion by 2150**
CFSC	**Medium and low project ions**	**Population reaches 7.8 to 8.1 billion by 2050 and is virtually stationary**
World Bank	**Standard**	**Population stabilizes at 9.8 billion by the year 2175**
Harvard	**Standard**	**Population reaches 8.4 billion by 2075 and is virtually stationary**

[a]These are unpublished, provisional estimates that are not official.

SOURCE: The Futures Group.

tion until some stationary level is reached. The second major difference is in the size of that stationary world population, which ranges from a low 8 billion (U.N. low, CFSC, Harvard) to a high of 14 billion (U.N. high). (The lower figures of World 3 and WIM are based on exceptional population programs begun in 1975, and are thus not comparable.)

There is much less variation in the population projections for 2000, which are compared in table A-2 and figure A-5. They vary from a low of 5.8 billion (Census Bureau, CFSC) to a high of 6.5 billion (U.N. and Census Bureau). This much smaller variation indicates the much higher degree of certainty inherent in population projection for periods under 25 years: there is relatively little uncertainty about the number of reproductive-age females between now and 2000, although there is much greater uncertainty with respect to the number of children that each woman will have.

The reasons for the differences among these different projections and their relative accuracy and reliability depend on several factors, among which are:

- projection technique;
- data base for initial population figures; and
- estimates of future fertility and life expectancy.

Table A.2.—Comparison of Population Projections for 2000

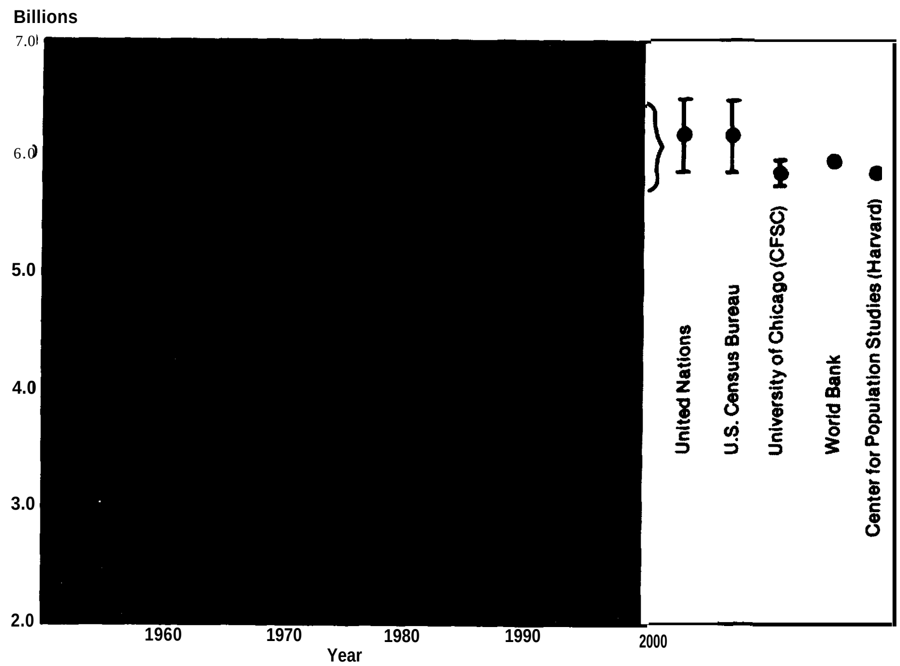
Projection source	Projection	Population in 2000 (billions)
World 3	Standard run	About 6
World Integrated Model	Standard run	6.4
Latin American World Model	Standard run	6.4
United Nations	High	6.5
	Medium	6.2
	Low	5.9
U.S. Bureau of the Census	High	6.5
	Medium	6.2
	Low	5.8
CFSC	High	6.0
	Medium	5.9
	Low	5.8
World Bank	Standard	6.0
Harvard	Standard	5.9

SOURCE: The Futures Group.

Projection Technique

The integrated models include the effects on population from other parts of the global system, and this results in the projection of increasing death rates due to food shortages in at least some parts of the world. The

Figure A-5.-Alternative Projections of World Population in 2000



SOURCES: *World Population Trends and Prospects by Country, 1950-2000. Summary Report of the 1978 Assessment* (New York: United Nations, 1979). *Illustrative Projection of World Population Projections to the 21st Century* (Washington, D.C.: Bureau of the Census, 1979). Amy Ong Tsui and Donald J. Bogue, *Population Projections for the World, 1975-2000* (Chicago: Community and Family Study Center, University of Chicago, October 1977). K. C. Zachariah and My Thi Vu, *Population Projections, 1975-2000 and Long-Term (Stationary Population)* (Washington, D.C.: Population and Human Resources Division, World Bank, 1979). Gary Littman and Nathan Keyfitz, *The Next 100 Years* (Cambridge: The Center for Population Studies, Harvard University, 1977.)

projections that did not employ global models assumed that such disasters would be prevented by technical change, but when forecasters are forced to specify their assumptions mathematically in a model, they were all drawn to similar conclusions: it is unlikely that technological advances alone will allow the world sufficient time to solve the problem of rapidly growing population. The technology assumptions or, indeed, the very structure of the models could well be wrong; but those who develop long-term population projections without the use of models have certainly side-stepped this issue. The problems identified by the integrated global models might be solved through improved technology or different social responses, but none of the projections prepared without models explicitly addresses these questions.

Data Base for Initial Population Figures

All of the recent projections use essentially the same data base for base-year population. Information from national sources is collected by the U. N., the World Bank, and the U.S. Census Bureau, and for most countries all three organizations report the same population totals. However, there is very little available information for some countries; it is therefore necessary to prepare estimates based on incomplete data, and these estimates may vary.

Uncertainty about base-year data is not expressed in the ranges reported by the U. N., and the Census Bureau projections incorporate different base-year data only for China. The recent round of censuses has substantially improved the information available for many countries, particularly in Africa, but for many countries the variation in estimates can still be quite large. China, for example, has not had a census since 1953, and there is a 14-percent difference between the U.N. low and Census Bureau high estimates for China in 1980, a difference about equal to the population of the United States. Similarly, the current population of Nigeria has been estimated at anywhere between 65 million and 85 million, and the most recent census in India found 12 million more people than expected. Even though these differences may be quite large for individual countries, however, they are fairly small once they are summed to the global level: the difference between the highest estimate for world population in 1975 (Census Bureau high series of 4,134 million) and the lowest estimate (World Bank estimate of 4,014 million) is only 3 percent.

Estimates of Future Fertility and Life Expectancy

It has generally been true that projection of populations for countries and regions is relatively accurate in the short term (15 to 20 years) and fairly inaccurate in the long term (over 25 years). The reason for this lies in the nature of population change. Population size changes through three mechanisms: births, deaths, and migration. Except for certain special *cases*, migration is usually not a major factor in population growth, although movements from rural to urban areas can have significant social, economic, and political consequences. Uncertainty in birth and death rates, on the other hand, can be quite large.

Changes in the birth rate have occurred quite rapidly in the past, and since the reasons for changes in the birth rate are poorly understood, projections of birth rates have tended to err on the side of assuming less change than actually takes place. However, even if the projection of the birth rate misses the mark by a significant amount, the short-term projection of the size of total population may still be reasonably accurate.

After 15 or 20 years, however, errors in projecting birth rates begin to have a much larger effect. By that time children born during the first years of the projections would begin to have children of their own, and any overestimation or underestimation of births will become compounded, leading to exponentially increasing errors in the projection. Since changing death rates affect the mortality of children much more than older age groups, this delayed compounding effect also operates on errors in death-rate projections. For this reason the record of population projections beyond 20 years has not been especially good.

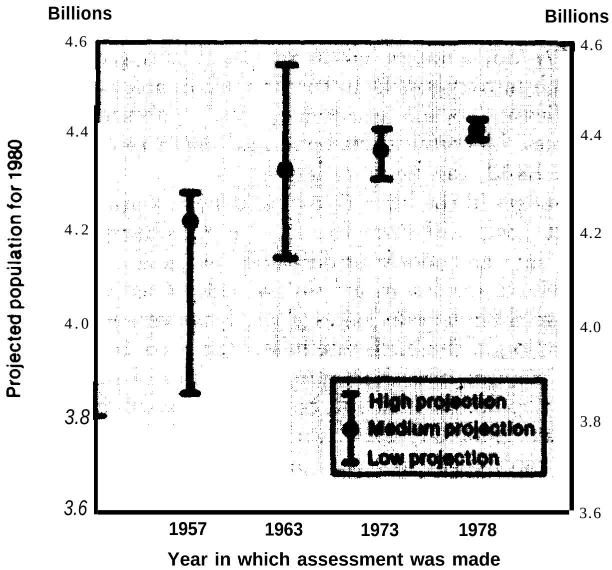
Another crucial factor is the accuracy of the base-year data for birth and death rates. If they are not known with much accuracy, then the projection will have a built-in error and, even if the future change in these rates is correctly forecast, the total error of the projection can be substantial. These factors most seriously affect projections for developing countries, where population data are often scant and unreliable.

The Accuracy of Past and Present Projections

The 1950's and 1960's were a period of rising population growth rates, and U.N. projections made during this period generally underestimated future population. Past U.N. projections of world population for 1980 illustrate this point: the latest assessment in 1978 projected the 1980 population at 4.41 billion; in 1957 it was projected at 4.22 billion (4.3 percent less than the latest estimate); in 1963 at 4.33 billion (1.8 percent less); and in 1973 at 4.37 billion (0.9 percent less) (see fig. A-6).

The major factor affecting these estimates was inaccurate base-year data on death rates, which were 10 or 12 percent lower than estimated. Birth rates, which were estimated more accurately for the base year, have declined more rapidly than predicted. The current esti-

Figure A-6.—United Nations Population Projections for 1960 Prepared Over the Past 25 Years



SOURCES: 1957 and 1963: *World Population Prospects* as *Assessed in 1963* (New York: United Nations, 1966), 1973: *Se/ecfed Wor/d Demographic Indicators by Countries, 1950-2000* (New York: United Nations, 1975). 1978: *Wor/d Popu/atlon Trends and Prospects by Country, 1950-2000, Summary of the 1978 Assessment* (New York: United Nations, 1979),

mates of population size, birth rates, and death rates are much improved over what they were in the 1950's and 1960's, but large uncertainties still remain, particularly with the LDCs.

The uncertainty over present birth rates also contributes to uncertainties about future birth rates. In the 1980-2000 period birth rates will probably decline for almost all 'countries of the world, but projecting the amount of that decline is made difficult by at least four factors:

- uncertainty about how much birth rates have already declined up to the present;
- uncertainty about how many countries will adopt serious family planning policies and how strong those efforts will be;
- uncertainty about how much family planning efforts have contributed to past declines in birth rates; and
- uncertainty about how relevant the experience of family planning effectiveness in countries that have already adopted such efforts will be in those countries which have not yet done so.

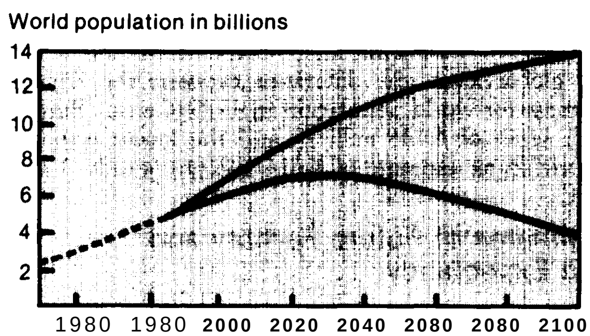
Most of the uncertainty is about birth rates in the developing countries, notably in Africa where there is almost no experience with strong family-planning programs. It is simply impossible to know whether the family-planning experience of countries in Asia and Latin America will be repeated in Africa.

Michael Stoto of Harvard University has calculated the average error in individual country projections made by the U.N. in 1957, based on the difference between predicted and actual growth rates for 40 countries for four time periods: 1955-60, 1955-65, 1955-70, and 1955-75. He found that the absolute average error in annual growth rates for all four time periods was about 0.46 percent, or about 25 percent of the absolute average annual growth rate for the world (about 1.9 percent).[9] The Futures Group has repeated these calculations for the period 1970-75, using projections made by the U.N. in 1973 and actual growth rates taken from its 1978 assessment, Using the same 40 countries, but eliminating those for which no new data are available since 1972, they found an absolute average error of 0.27 percent. Most of the improvement is probably due to the improved quality of base-year data available for the 1973 forecasts, which were used in UNIOWM, If these errors are representative of the kind of errors we can expect in the future, projections of population size 20 years into the future should have an uncertainty range of 10 to 20 percent.

In the longer term the accuracy is much lower. This is due to the greater uncertainty about fertility and mortality trends, the compounding of errors made in the short-term forecasts, and uncertainty about the effects of the rest of the world system (food availability, economic development, pollution) on population growth. The range of projections shown in the studies discussed here–from a projection of steadily growing population reaching a level of 8 to 14 billion, to a projection of population growth and collapse—is representative of the kind of uncertainty that exists in trying to project 50 to 100 years into the future, even if we are willing to exclude such disasters as nuclear war (see fig, A-7).

[9] J. Stover, op. cit.

Figure A.7.—Increasing Range of Uncertainty in Longer Range Projections of World Population



NOTE: For illustrative purposes only; see table A-1 and text for explanation.
SOURCE: Office of Technology Assessment.

APPENDIX B

Agricultural Projections

Introduction

World food supply has been a major concern for global modelers. All of the well-known global models have one or more agricultural sectors; all of them consider measures of food availability as major indices of system performance; and all indicate that performance of the global agricultural system over the next 20 to 100 years is a matter of concern. The apparent discrepancies in their findings result from differences in time horizons, model structure, assumed rates of population and economic growth, the pace of technological progress, and assumptions about the quantity of agricultural land available.

In general, the most optimistic findings come from assumptions of high income growth, low population growth, continued rapid technological progress, and large reserves of agricultural land. Longer time horizons, however, lead to more pessimistic results; and those models that include diminishing returns to land and agricultural inputs show the situation in the global agricultural system getting tighter as time progresses, with South Asia and Sub-Saharan Africa the most severely affected regions.

Purposes, Structures, and Findings

World 3

The World 3 model was intended to examine the interactions between a set of global trends and to identify the long-term impact of their interdependent evolution. as a result, the World 3 model assumes that agriculture must compete with the industrial and service sectors for investment capital and natural resources, and it contains a mechanism by which capital and resources flow to sectors that show signs of supply shortfalls. The model also assumes diminishing returns for investments in land development and agricultural inputs, such as fertilizer and farm machinery; but it excludes both the price mechanism and "disembodied technological progress" (see below). The model does assume, however, that soil degradation and pollution will have negative effects on yields.

In the standard run (see fig. B-1), all indices of agricultural performance improve until the second decade of the next century. Yields and land under cultivation both make considerable gains between 1980 and 2000, and food per capita increases 10 percent despite rapid population growth. Around 2015, however, at about the same time that the limits of arable land are reached, industrial growth so depletes the resource base that investment must be shifted away from agriculture in order to compensate for the increasing costs of resource extraction (see fig. B-2). Industrial output declines, as does the use of agricultural inputs, causing both yields and total production to decline more rapidly in the 21st century than they had expanded in the 20th century (see fig. B-3). Since population continues to increase, the result is widespread hunger, mass starvation, and a delayed but catastrophic decline in global population.

World 3 produces different projections when plausible changes are made in its assumptions, but although the timing of events may be changed by a few decades the net result is the same. For example, given more optimistic assumptions about industrial resources and/or more pessimistic assumptions about agricultural resources, agricultural decline causes investments and resources to be drawn away from industry rather than vice versa; but decline feeds on decline and mass starvation ensues. However, one group of critics reports that they have been able to move the physical limits to agricultural production beyond the time horizon of the model by assuming continuing technical progress in both land-development techniques and high-yield plant varieties, as well as a more rational use of agricultural resources.[2] The structure of World 3 is not sufficiently detailed or flexible, however, to determine what specific policy actions this might entail. Its sensitivity to resource depletion in other policy tests also suggests that the world agricultural crisis, though moved beyond 2100, might still occur.

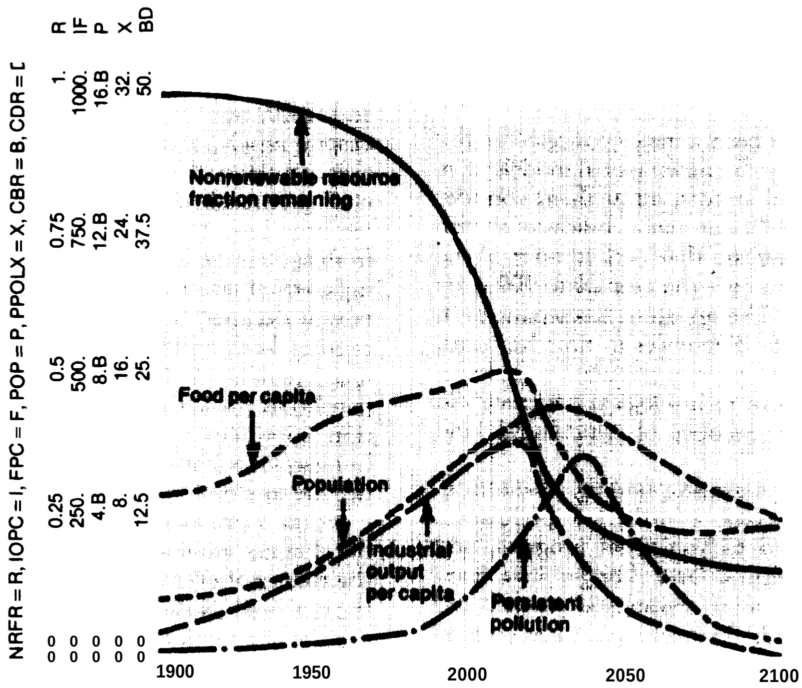
World Integrated Model (WIM)

WIM'S projections have greater relevance for food policy analysis because its structure allows a region-by-region investigation of the interaction between population, agriculture, and industrialization. WIM goes into more detail than World 3 and also includes both the price mechanism and a simulation of food and other trade between regions. Environmental effects have been excluded, but the shortened time horizon—2025—is still long enough to encompass the crises foreseen by World 3. WIM also includes numerous "policy levers," making

[1]The following material is based on an OTA working paper prepared by Jennifer Robinson, a fellow of the International Institute of Applied Systems Analysis. For further Information on this subject, see OTA's forthcoming assessment, The *Impact of Technology on the Productivity of the* Lund

[2]H. S. D. Cole (cd.), *Models of* Doom (New York: Universe Books, 1973), p. 64.

Figure B-1.—Output From Standard Simulation of World 3



NOTE: Around 2015 the rapid decline of nonrenewable resources forces the industrial sector to shift investments away from industrial and agricultural production to compensate for increasing resource extraction costs. This causes declines in industrial output and agricultural production. The latter, in turn, causes massive starvation and decline of global population by nearly 3 biillon over the period 2030-2100.

SOURCE: *Dynamics of Growth in a Firtite Wor/d,* pp. 501-s03.

it a flexible tool for testing different combinations of actions that could be taken to address potential food supply problems.

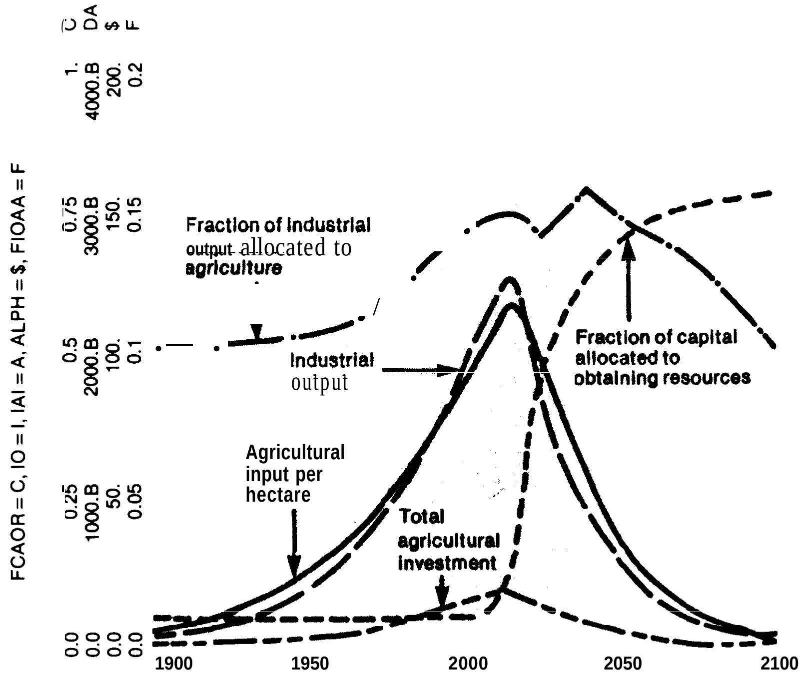
The WIM standard or "historical" scenario is based on a continuation of present trends, but it nevertheless makes some rather optimistic assumptions about agricultural progress in the developing regions. (The report focuses on South and Southeast Asia because of this region's existing food problems and the number of people involved, but the authors assert that their conclusions "are applicable to Tropical Africa and to any other needy region. "[3] It assumes, for instance, that all available arable land is quickly brought under cultivation and that all technological inputs, such as irrigation systems and farm machinery, will be available as needed. It also assumes "quite optimistically" that the average use of fertilizer per hectare in the region will surpass the present North American level by 2025, at which time South Asia alone will be consuming more fertilizer per year than the entire world consumed in 1960. These factors increase yields by about 1,000 kg per hectare, approximately the same increase achieved by the Green Revolution on the best land before fertilizer prices began to soar. Finally, the standard run assumes that other regions make enough food available to cover any production shortfall in South Asia.[4]

Despite these assumptions, however, and despite the assumption that population will stabilize by 2025, the food supply projections for South Asia are grim (see fig. B-4). The region's annual protein production increases by two-thirds, but the population almost triples and the annual protein deficit grows from 12 million to 50 million tons–an amount equal to the region's own production. Deficits amounting to half the region's protein needs "could never be closed by imports, " according to the authors: paying for them would require one-third of South Asia's total economic output and three times its export earnings, and "the physical problems of handling those quantities of food would be incredible."[5] Even if the needed imports were available, the annual

[3]M. D. Mesarovic and E, Pestel, *Mankind at the Turning Point* (New York: Dutton, 19 T-1), p. 121.

[4]Ibid., p. 121.
[5]Ibid., p. 122.

Figure B-2.–Output From Standard Simulation of World 3



NOTE: Around 2015 the rapid decline of nonrenewable resources forces the industrial sector to shift investments away from industrial and agricultural production to compensate for increasing resource extraction costs. This causes declines in industrial output and agricultural production. The latter, in turn, causes massive starvation and decline of global population by nearly 3 billion over the period 2030-2100.

SOURCE: *Dynamics of Growth in a Finite World,* pp. 501-503.

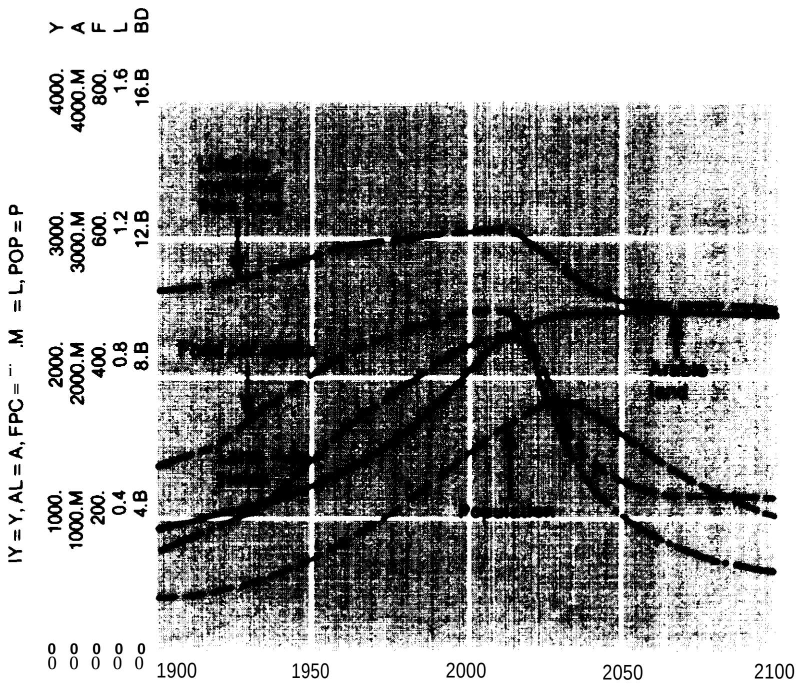
number of child deaths caused by malnutrition will double by 2005 (see fig. B-5).

Policy tests conducted with WIM indicate that only a combination of food aid, population policies, and balanced development can avert tragedy in South Asia. In the "isolationist" or "tragic" scenario, in which food imports are not available because of balance-of-payments constraints, annual child mortality is twice as high as in the standard run; it rises sharply after 1985, peaks in 2010, and declines thereafter only because of the delayed impact of earlier deaths on the later number of fertile women (see fig. B-5). A third scenario, designed to investigate policies aimed at food self-sufficiency for South Asia, assumes that virtually all regional investment is shifted from industrial development to agriculture; but the results indicate that yields per hectare, after initially rising faster than in the standard run, would peak around 2000 and decline thereafter. This decline occurs because the agricultural sector would not be able to maintain its growth without the industrial base that must supply it with fertilizer and machinery. By 2025, gross regional product is only half what it was in the standard run, and the region is left with even fewer means of paying for food imports.

In further policy tests, WIM shows that population policies aimed at achieving an equilibrium fertility rate could have a significant effect on food deficits and child mortality, even in the absence of imports, if they are implemented quickly enough. Such policies, if initiated in 1995, would not reduce the number of child deaths in the "isolationist" scenario; if initiated in 1990, however, the same policies-might save more than 150 million lives (see fig. B-5). If initiated in 1975, these policies could avoid more than 500 million child deaths.[6] The need for food imports would be significantly reduced and would come later in the period, but the cost would still be prohibitive. In a final scenario, therefore, it is assumed that the developed regions provide South Asia with sufficient investment aid to develop "its own exportable and competitive industrial specialization, " whose exports could pay for most of its food imports.[7]

[6] Ibid., p. 124 and fig. 9-9.
[7] Ibid., p. 127.

Figure B-3.—Output From Standard Simulation of World 3



NOTE: Around 2015 the rapid decline of nonrenewable resources forces the industrial sector to shift investments away from industrial and agricultural production to compensate for increasing resource extraction costs. This causes declines in industrial output and agricultural production. The latter, in turn, causes massive starvation and decline of global population by nearly 3 billion over the period 2030-2100.

SOURCE: *Dynamics of Growth in a Finite Wor/d,* pp. 501-503.

Latin American World Model (LAWM)

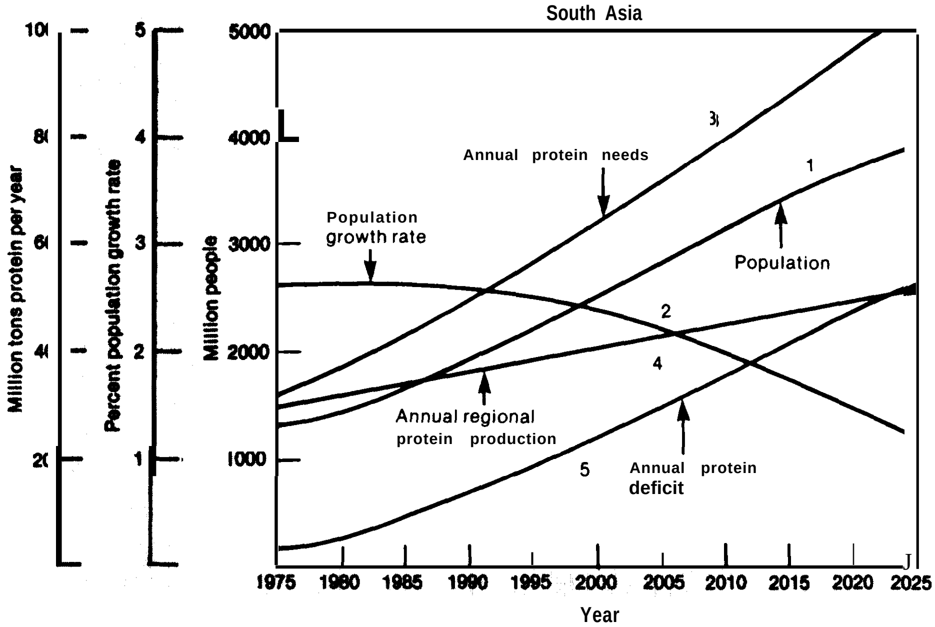
LAWM was developed to show that, given optimal resource allocation and the universal objective of satisfying basic human needs, the global system need not be troubled by physical limits. Because development proceeds "autarchically" in each of its four regions, international food trade is unimportant and is largely excluded from the model. Environmental effects are also omitted, as are food prices; and although the model assumes diminishing returns on land development and yield-enhancing inputs, it also assumes "disembodied technological progress" (see below) in the form of an automatic I. O-percent annual increase in the productivity of the food and agriculture sector.

The food and agriculture sector is by far the most complicated in LAWM, containing three subsectors —agriculture, livestock, and fisheries–among which capital and labor are allocated in patterns that shift over simulated time as the return on investment diminishes in each. Each of these subsectors contains at least one optimistic assumption. The agriculture subsector, for instance, assumes that fertilizer will be available in unlimited quantities and at constant prices throughout the simulation period, and that processing losses in the developing regions will decrease automatically each year until they reach the levels currently found in the developed region. Similarly, the livestock subsector assumes that agricultural wastes and excess agricultural products will be used for animal fodder once human needs are met, thereby transforming food wastes into a measure of meat consumption. The fisheries subsector assumes a maximum sustainable catch of 120 million metric tons per year, considerably higher than the level indicated by more recent reports.

The model assumes no policies to limit population growth, other than the general improvement of living conditions. However, it does assume a radical, egalitarian redistribution of income and consumption within regions, which greatly increases the effective demand and relative benefit for the lowest socioeconomic strata.

Given these optimistic assumptions, the standard run of this optimization model indicates that all regions except Asia will be able to satisfy their own food needs

Figure B-4.—World Integrated Model Standard Run for South and Southeast Asia



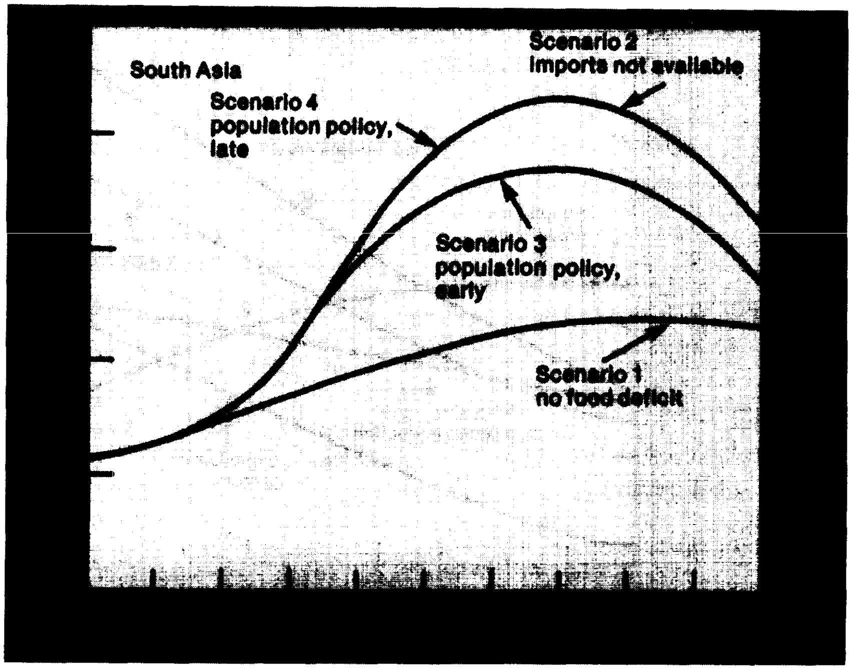
The "standard" scenario is based on the assumption that a population policy is initiated that leads in about 50 years to equilibrium fertility. Thereby, the population grows from 1.3 billion in 1975 to 3.8 billion in 2025 (curve 1) while the growth rate of this region declines from a little over 2.5 to 1 percent (curve 2). It is furthermore assumed that the population is adequately fed, and thus no starvation would slow down the population growth. Then the protein needs (curve 3) of South Asia would increasingly surpass her own protein production (curve 4) so that at the end of the 50 year period considered, the protein deficit (curve 5) is larger than her own estimated protein production of around 50 million tons. The grain import necessary to cover this protein deficit (due to the fact that more than 90 percent of all the protein consumed in South Asia is of vegetable origin this is also a calorie deficit) would increase to about a half billion tons annually by 2025 and would continue to grow. This amount is twice the present North American grain crop, and even if it were available for export to South Asia, it would pose practically insurmountable transportation and distribution problems. The increase of the regional production in South Asia is based on making all potentially arable land available for cultivation and on achieving a steadily rising yield per hectare. These production levels assume productivity comparable to that achieved by introduction of improved grains — the "Green Revolution" — on the best irrigated land in India, which is probably an overly optimistic assumption.

SOURCE: *Mankind at the Turning Point*

within 30 years. The agriculturally relevant variable in the simulation outputs is the total daily caloric intake per capita: in the developed nations, it rises to 3,200 calories by 1980 and equilibrates at that level thereafter (fig. B-6); in Latin America it rises to 3,000 calories by 1990 and stabilizes at that level, which is lower due to differences in climate and diet (fig. B-7); Africa achieves and stabilizes at a similar level around 2008. In Asia, however, the only need that is met is education; food per capita peaks at less than 3,000 calories per day in 2010 and declines steadily thereafter (fig. B-8). This agricultural collapse is similar to the catastrophe foreseen by WIM in both its standard and self-sufficiency runs:

> The problem in Asia arises in the food sector. By 2010, all available land is being cultivated. Thereafter, economic effort in the sector is devoted to increasing livestock and fisheries. This, however, is not enough to feed the growing population adequately, and consumption drops rapidly to below the minimum needed for survival.
>
> The rapid increase in the cost of producing food, due to the development of new land for agriculture, takes resources from the rest of the economy, causing backward-

Figure B-5.—Child Mortality in Four Scenarios of the World Integrated Model



Scenario 1 is the standard scenario. Scenario 2 shows the consequences for Scenario 1 if imports are not available to cover the protein deficiency gap. Scenario 3 shows the reduction in child mortality achieved over Scenario 2 by a population policy instituted in 1990. Scenario 4 shows the consequences of implementing the same population policy 5 years later. Composite of Figures 9-2 and 9-4, *Mankind at the Turning Point,* **pp. 122 and 128. The projection of Scenarios 2 and 4 are essentially identical in the original.**

SOURCE: *Mankind at the Turning Point,*

> ness and also hindering the satisfaction of the other basic needs. In summary, the delay in reaching adequate levels of well-being leads to a sustained high population growth rate, and a vicious circle develops: increased population and the increased cost of producing food make it more and more difficult to satisfy basic needs.[8]

Rather than show the full details of this catastrophe, the modelers have truncated the Asia run at 2040, 20 years before simulations for other regions are terminated. The authors advocate effective population policies and the use of nonconventional foodstuffs to avoid mass starvation in Africa, but then present neither specific details nor policy tests to support these recommendations.

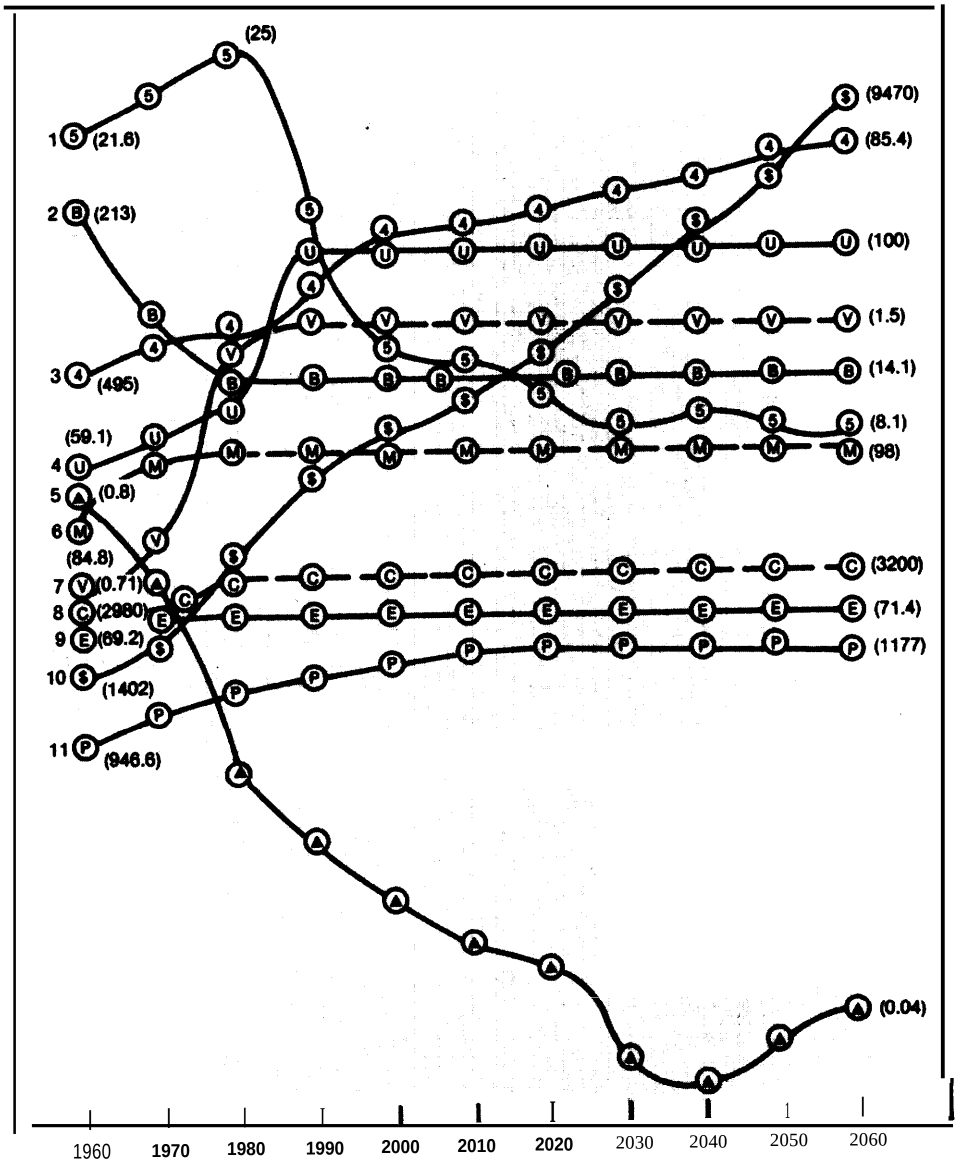
The policy tests that were conducted by the LAWM team indicate that capital transfers from the developed region would have a negligible impact on the food shortage in Asia. They also show that technological stagnation after 1980 would lead to a similar collapse in Africa as well as Asia and that, in the absence of regional income redistribution, the satisfaction of basic needs (though possible) would require three to five times more resources and two to three more generations of human suffering.

United Nations Input-Output World Model (UNIOWM)

UNIOWM is the only model that does not indicate potential problems in supplying food to all the world's people over the next two decades. Its optimistic findings, however, result in part from its purpose and structure: its projections do not show what is likely to happen in the agricultural sector, but rather what trends would be required in order to achieve the goals of the U.N.'s Second Development Decade. The input-output approach is well suited for consistent accounting of intersectoral flows, but it is not particularly well adapted for agricultural analysis because it is totally linear. Many biological processes, on the other hand, are

8A. O. Herrera, et al,, *Catastrophe or New Society? A Latin American World Model* (Ottawa: international Development Research Center, 1976), p. 29.

Figure B-6.—Time Period and Conditions Required for Developed Countries to Satisfy Basic Needs to Given Levels

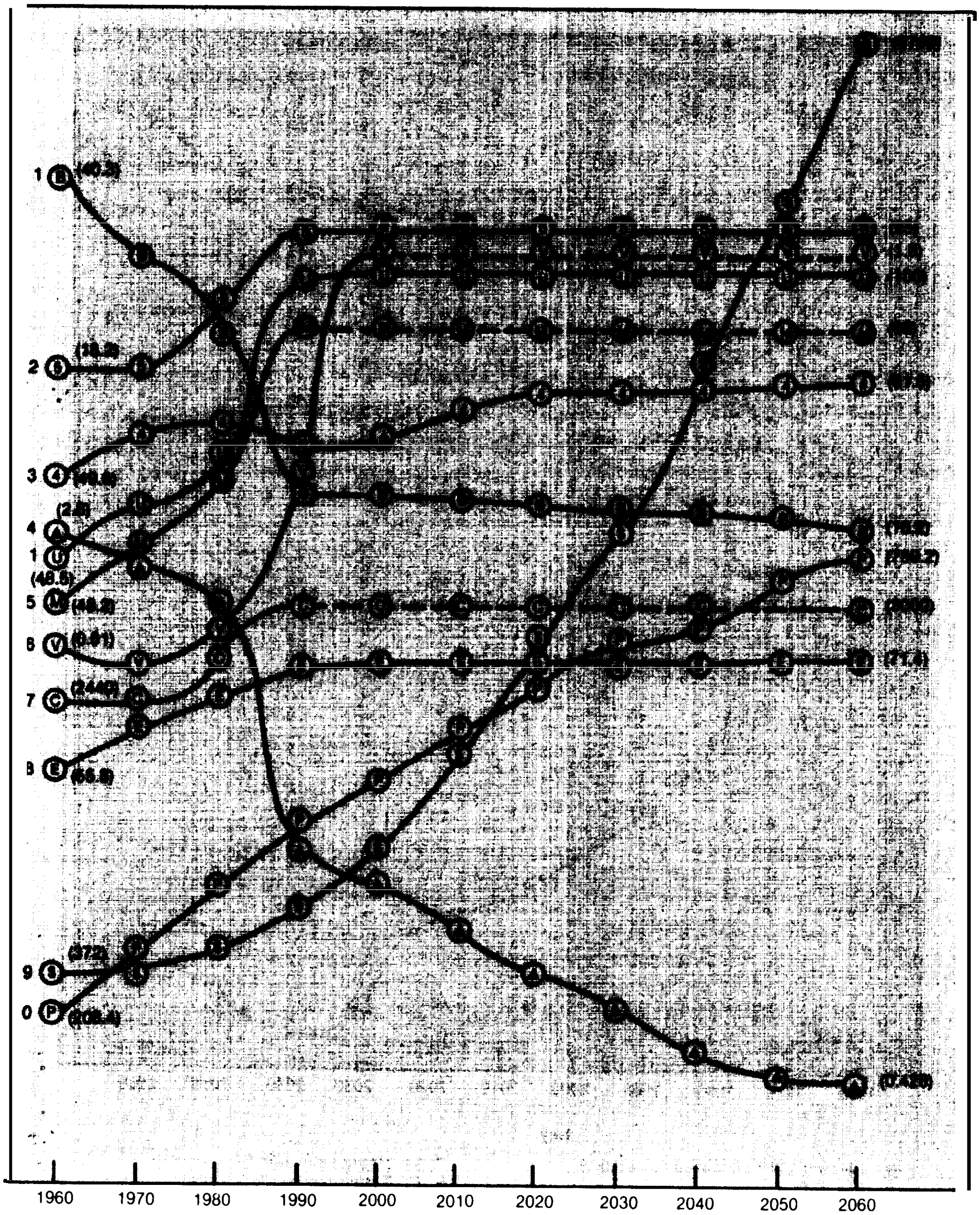


Key:

1 (5) Percent GNP allocated to sector 5
2 (B) Birthrate
3 (4) Percent GNP to other goods and services
4 (U) Urbanization
5 (A) Population growth rate
6 (M) Enrollment
7 (V) Houses per family
8 (C) Total calories per capita
9 (E) Life expectancy
10 ($) GNP per capita
11 (P) Total population

SOURCE: Catastrophe or New Society[a]

Figure B-7.—Latin American World Model Simulation for Latin America

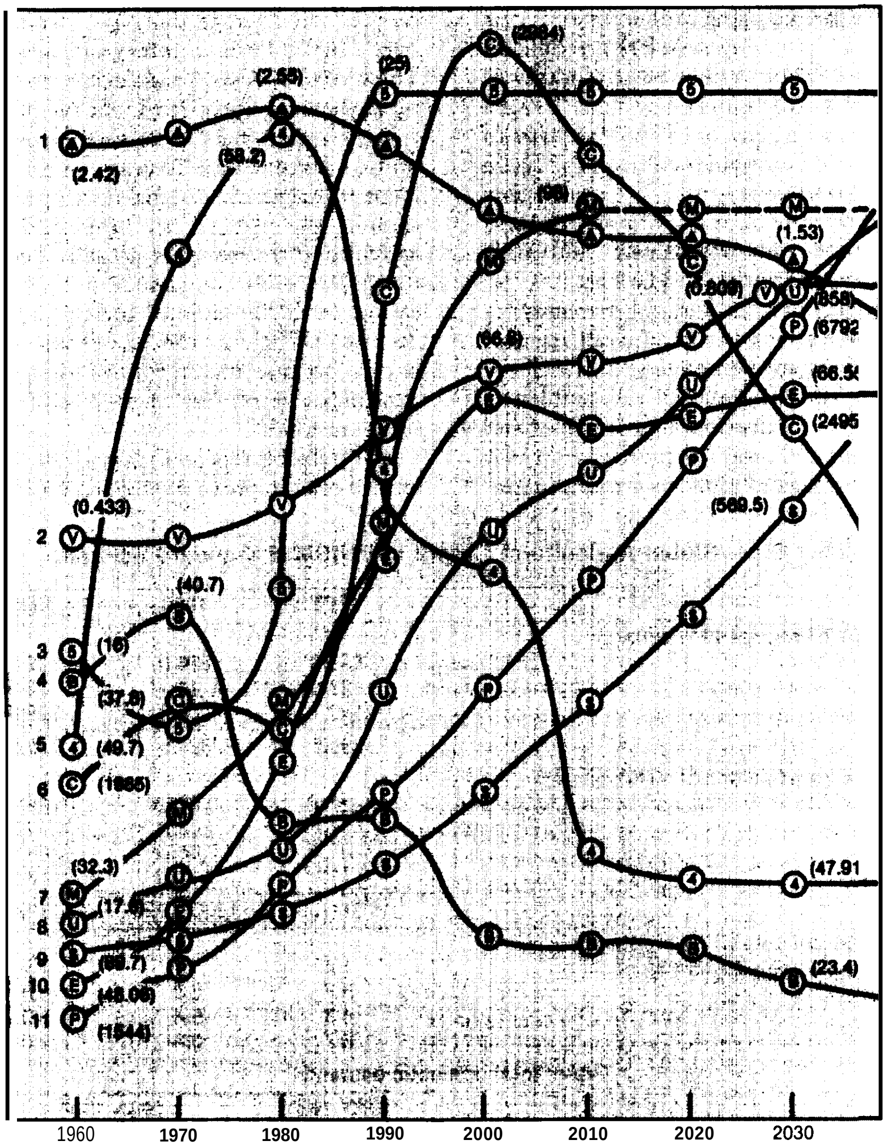


Key:

1 (B) Birthrate
2 (5) Percentage of GNP allocated to sector 5
3 (4) Percentage of GNP allocated to sector 4
4 (A) Population growth rate
5 (M) Enrollment
6 (V) Houses per family
7 (C) Total calories
8 (E) Life expectancy
9 ($) GNP per capita in 1960 dollars
10 (P) Total population
11 (U) Urbanization

SOURCE: *Catastrophe or New Society?* p. 88

Figure B-8.— Latin American World Model Simulation for Asia



Key:

1 (A) Population growth rate
2 (V) Houses per-family
3 (5) Percentage of GNP allocated to sector 5
4 (B) Birthrate
5 (4) Percentage of GNP to other goods and services
6 (C) Total calories per capita
7 (M) Enrollment
8 (U) Urbanization
9 ($) GNP per capita in 1960 dollars
10 (E) Life expectancy
11 (P) Total population

SOURCE. *Catastrophe or New Soc/ety?* p. 92.

highly nonlinear, and many critical agricultural flows (such as the externalities associated with overgrazing and deforestation, or the changing probabilities of pest damage under different cropping systems) are difficult to include in an input-output framework. In addition, UNIOWM shows linear returns on investments in agricultural inputs and must depend on off-line analysis to determine the amount of land under cultivation. These features produce odd results in some places, such as a 169-percent increase in the productivity of Japanese farmlands, which are already intensively cultivated, and a 387-percent increase in the Middle East.

In general, the projections show rapid increases for almost all agricultural variables in almost all regions, with the most dramatic gains being made in the developing countries. Over the 30 years of the simulation (1970-2000), global grain production almost triples and global production of animal products more than triples (table B-1). Developing regions achieve astounding increases in both land productivity and total agricultural production (table B-2), and by 2000 all regions have reached an average daily per capita consumption of over 2,400 calories and 66 grams of protein (table B-3). These results, however, do not seem to be accompanied by any symptoms of economic or financial stress. Agricultural prices, relative to general price levels, increase only 14 percent *over* 30 years. In no region does investment in irrigation or land development grow by more than a few percent per year, and in many regions agricultural investments actually decline. If anything, the pressure on the agricultural system appears to be easing in 2000: rates of agricultural demand growth decrease slightly in the last decade of the simulation, largely because incomes have risen to a point where consumers spend less of each additional dollar of income on food.

It should be repeated that these projections are intended only to prove the technical and *physical* feasibility

Table B- l.—Global Agricultural Output in UNIOWM Standard Scenario

	1970	1980	1990	2000
Total agricultural output (billions of 1970 dollars):				
Developed	255.8	296.0	332.2	415.4
Developing group I[a]	23.8	42.1	78.5	151.7
Developing group II	120.1	186.4	322.8	529.9
World	399.7	524.5	733.5	1097.0
Agricultural output per capita (billions of 1970 dollars):				
Developed	0.2615	0.2776	0.2878	0.3381
Developing group I	0.0665	0.0884	0.1222	0.1770
Developing group II	0.0526	0.0652	0.0910	0.1227
World	0.1104	0.1192	0.1372	0.1713
	1970-1980	1980-1990	1990-2000	1970-2000
Rate of growth of agricultural output[b] (percentage):				
Developed	1.4	1.2	2.2	1.6
Developing group I	5.7	6.2	6.6	6.4
Developing gourp II	4.3	5.4	5.0	5.1
World	2.7	3.4	4.0	3.4
Grain: total domestic demand				
	1970-1980	1980-1990	1990-2000	
Rate of growth[b] (percentage):				
Developed countries	1.6	3.4	2.1	
Developing group I	3.7	5.3	6.3	
Developing group II	3.6	4.6	4.4	
World	2.7	4.1	3.7	
Animal products: total domestic demand				
	1970-1980	1980-1990	1990-2000	
Rate of growth[b] (percentage):				
Developed countries	2.25	2.26	1.34	
Developing group I	5.53	5.73	6.55	
Developing group II	4.33	4.93	4.82	
World	3.13	3.54	3.40	

[a]Group I includes mineral rich developing countries; group II is comprised of mineral poor developing countries.
[b]Average annual compound.

SOURCE: *The Future of the World Economy*, pp. 39, 42, 43.

Table B-2.–Land Requirements and Yields in 2000 in UNIOWM Standard Scenario (Index, 1970 = 100 percent)

Region	Agricultural output	Arable land	Land productivity
Developed market:			
North America	196	111	194
Western Europe (high-income)	130	100	162
Japan	176	100	269
Oceania	192	183	162
Centrally planned:			
Soviet Union	164	100	215
Eastern Europe	143	100	186
Asia (centrally planned)	468	120	278
Developing market:			
Latin America (medium-income)	495	166	311
Latin America (low-income)	532	140	328
Middle East	950	126	487
Asia (low-income)	506	113	331
Africa (arid)	409	131	282
Africa (tropical)	438	152	324

SOURCE: *The Future of the Wor/d Economy,* p. 40.

Table B-3.—Regional Daily per Capita Food Consumption in 1970 and 2000, UNIOWM Standard Scenario

Region	Kilo-calories (thousands) 1970	2000	Proteins (grams) 1970	2000
Developed market:				
North America	3.2	3.2	96	100
Western Europe (high-income)	3.0	3.2	91	105
Japan	2.4	3.2	71	117
Centrally planned:				
Soviet Union	3.2	3.2	92	108
Eastern Europe	3.1	3.2	93	108
Asia (centrally planned)	2.1	2.5	59	79
Developing market:				
Latin America (medium-income)	2.4	3.0	60	86
Latin America (low-income)	2.2	2.9	50	74
Middle East	2.0	2.9	53	92
Asia (low-income)	2.0	2.4	52	66
Africa (arid)	2.5	2.5	72	78
Africa (tropical)	2.2	2.8	62	87

SOURCE: *The Fufure of the World Economy,* p. *39.*

of certain U.N. development goals The modelers involved in the UNIOWM have tended to merely state their findings and allow readers to draw their own policy conclusions. Like WIM and LAWM, however, their model points to the need for increased food self-sufficiency and export earnings in the LDCs. Findings relevant to food and trade policy include the following:

> The most pressing problem of feeding the rapidly increasing population of the developing regions can be solved by bringing under cultivation large areas of currently unexploited arable land and by doubling and trebling land productivity. Both tasks are technically feasible but are contingent on drastic measures of public policy favorable to such development and on social and institutional changes in the developing countries.[9]
>
> Self-sufficiency in food is a promising kind of "import substitution" for reducing balance of payments deficits in developing countries.[10]
>
> A relatively stable increase in the prices of minerals and agricultural goods exported by the developing countries, as compared to the prices of manufactured goods, is one way of increasing the export earnings of these countries and closing their balance of payments deficit . . . . For developing regions which are not large net exporters of minerals or agricultural goods, the main way to reduce the potential trade imbalance is to significantly decrease their import dependence on manufactured products . . . while . , . increasing their share of world exports of some manufactured products, particularly those emanating from light industry. . . . Increase in aid; measures to create a more favorable climate for a better mix of capital investment flows to these regions; [and] . . . reduction in the financial burden arising from foreign investment are important, but . . . secondary . . . compared to . . . changes in the commodity markets and trade in manufactured products.
>
> 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.[11]

Global 2000

The agricultural projections in Global 2000 were generated by the grain-oilseed-livestock (GOL) model that was developed in 1974 by the U.S. Department of Agriculture (USDA) to assist in the formulation and execution of U.S. agricultural and trade policy. Maintained by the Foreign Demand and Competition Division of USDA's Economics, Statistics, and Cooperative Service, GOL is a computer-based static equilibrium econometric model that was specifically designed to capture the interaction between the largely cereal-oriented food economies of the developing regions and the livestock-oriented food economies of the industrialized regions. For the purposes of Global 2000, GOL was supplemented with three independently developed submodels that project the availability of 'arable land, the total food supply (including fisheries and other miscellaneous sources), and the use of fertilizer in each region. GOL has been used to analyze the potential impact of U.S. parity pricing policies on international food trade and to analyze the potential impact of alternative assistance programs for the U.S. Agency for International Development.

[9] W. Leontief, et al., *The Future of the Wodd Economy* (New York: Oxford, 1977), p. 21.
[10] Ibid., p. 22.
[11] Ibid., p. 23.

The greatest advantage of the GOL is its scope and detail: it consists of 28 interactive regional submodels containing equations for the supply, demand, trade, and prices of 16 different food commodities. USDA analysts claim that the model represents 70 to 80 percent of world production and consumption and an even larger percentage of food trade. Its greatest weakness is that, as a static equilibrium model, it is incapable of representing market behavior that is in disequilibrium. In addition, dynamic factors such as population and income growth must be calculated exogenously in advance and thus are not affected by the model's operation. These factors were adjusted to be more consistent with other sectors of Global 2000, but a number of minor discrepancies exist between the GNP and population projections and the corresponding GOL assumptions. Other critical assumptions incorporated into GOL include the following:

- no major wars, changes in the international economic order, or natural disasters such as climatic change or large-scale land degradation;
- no increase in world grain reserves to keep pace with population growth, no change in Western Europe's somewhat protectionist agricultural and trade policies, and no major increase in U.S. food trade with the Soviet Union, Eastern Europe, or the People's Republic of China; and
- continued technological progress (measured in yields) comparable to: the rapid growth of the last 20 years, with the industrialized nations and (to a lesser extent) the LDCs taking advantage of technology according to the incentives provided by changes in the prices of production factors and food commodities.

GOL generated four alternative sets of agricultural projections for Global 2000, using different assumptions about population, income, weather, and energy prices:

- Alternative 1, the standard or "baseline" projection, assumes medium rates of population and income growth, constant weather, and constant real energy prices at 1974-76 levels.
- Alternative IA, a variant of the standard run, assumes a doubling of real energy prices by 2000.
- Alternative II, the optimistic upper-bound projection, also assumes constant real energy prices, but assumes lower population growth and higher per capita income growth, as well as more favorable weather conditions than over the last 25 years.
- Alternative 111, the pessimistic lower bound projection, assumes a doubling of real energy prices, higher population growth, lower income growth, and less favorable weather conditions.

Detailed regional projections for 1985 and 2000 of total and per capita grain and food production, consumption, and trade are presented in tables B-4 and B-5. "Other African LDCs" are included in order to show the model's most problematic region, and South Asia is included to allow comparison with the results of other global models. World grain production and regional per capita consumption figures are compared in figures B-9, and B-10, which illustrate the range of uncertainty that results from different exogenous assumptions. In case of energy variables, according to the report, "[the] range reflects not so much uncertainty about petroleum price increases as uncertainty about . . . the ability of farmers to maintain or expand production while shifting away from energy-intensive inputs."[12]

Within this range, the results indicate a near doubling of global food supply between 1970 and 2000. Roughly speaking, this comes from a 50-percent increase in the developed regions and a 150-percent increase in the LDCs. In both cases the increase comes from fertilizer use rather than land development: global cultivated land increases less than 5 percent by 2000, whereas the application of fertilizer per hectare increases 160 percent, doubling in the developed regions and quadrupling in the LDCs. However, because population growth is more rapid in the LDCs than in the developed regions, LDC consumption generally increases more rapidly than production. As a result, international food trade will expand ,briskly, with the United States and Argentina benefiting most from the larger markets (see table B-6). Gains in per capita consumption are small and unevenly distributed in the LDCs: Tropical Africa shows net declines in per capita food consumption even in the most optimistic scenario, and gains in South Asia are less than 10 percent at best; on the other hand, per capita increases of 10 to 30 percent are projected for Latin America and East Asia. The real price of food on the world market is projected to increase by between 30 and 115 percent, depending on the scenario; under the higher figure, the poorest LDC importers could find themselves priced out of the market as they were in 1973-75.[13]

These findings lead to several conclusions relevant to food policy. The world has the physical and economic capacity to meet substantially increased food demand through 2000, but to do so it must maintain the near-record growth rates of the 1960's and 1970's. Significant increases in food trade will be needed to balance excess demand in food-deficit Western Europe, Japan, and the centrally planned economies, as well as parts of developing Africa and Asia. Variations in supply will become more important as the world's productive capacity is used at higher levels, particularly if there is no increase in world grain reserves. This suggests, according

[12] *The G&d 2000 Report to the President* (Washington, D. C.: U.S. Council on Environmental Quality and Department of State, 1980), vol. 2, p. 85.
[13] Ibid., vol. 2, p. 556.

Table B-4.–Grain and Total Food Production, Consumption, and Trade (Alternatives 1, II, III) As projected by the GOL Model for Global 2000

	1985						2000					
	Grain (million metric tons)			Food (1969-71 = 100)			Grain (million metric tons)			Food (1969-71 = 100)		
	I	II	III	I	II	III	I	II	III	I	II	III
Industrialized countries:												
Production	569.5– 525.9	568.1	536.2	126.6- 118.1	127.3	118.2	739.7– 679.1	730.0	683.3	157.0- 143.7	157.1	143.5
Consumption	486.2– 465.3	515.7	455.9	121.0 -116.6	127. ?	114.6	848.4- 610.8	687.6	590.2	155.8- 147.7	165.7	143.6
Trade	+ 83.3– + 60.6	+ 52.4	+ 60.3				+ 91.3– + 68.3	+ 42.4	+ 93.1			
United States:												
Production	304.0– 297.1	297.5	309.7	137.8 -134.9	135.1	140.2	416.0- 402.0	409.8	414.0	184.3 -178.5	181.8	183.5
Consumption	210.9– 199.8	229.5	194.4	119.6 -114.0	129.2	111.2	290.2- 272.4	+325.0	+256.8	160.3 -151.3	178.3	143.2
Trade	+ 93.1– + 97.3	+ 68.0	+ 115.3				+ 126.0- + 129.6	+ 84.6	+ 157.2			
Centrally planned countries:												
Production	567.0	589.5	534.0	138.2	143.7	130.1	722.0	746.0	691.0	174.0	179.5	166.1
Consumption	596.0	597.5	578.5	143.3	143.8	139.1	758.5	755.0	730.0	179.9	179.2	173.2
Trade	– 29.0	– 6.0	– 44.5				– 36.5	– 9.0	– 39.0			
Less developed countries:												
Production	471.7– 490.7	485.3	470.5	154.4 -161.4	158.9	152.9	735.0– 740.6	757.0	745.3	244.5- 247.7	266.2	246.4
Consumption	526.0– 522.3	529.7	506.3	163.4 -162.8	165.1	157.1	789.8– 772.4	790.4	799.4	247.8 -242.6	261.2	249.0
Trade	– 54.3– – 31.6	-44.4	-35.8				– 54.8– – 31.8	– 33.4	– 54.1			
Latin America:												
Production	101.0– 111.9	104.3	107,6	158.7 -174.8	163.6	168.4	182.6– 185.9	195.4	188.4	279.5-284.4	298.4	288.1
Consumption	99.5– 98.2	103.7	97.2	162.7 -160.7	169.2	159.2	168.8– 166.0	172.5	160.6	269.7 -265.3	275.4	257.0
Trade	+ 1.5– + 13.7	+ .6	+ 10.4				+ 13.8– + 19.9	+ 22.9	+ 27.8			
North Africa/Middle East:												
Production	56.2– 56.8	57.3	53.0	146.3- 148.1	149.6	136.9	92.2- 89.0	94.5	88.1	252.5 -257.8	259.3	240.4
Consumption	80.6– 79.6	60.9	79.9	167,4 -165.1	168.1	165.8	127.5- 123.7	125.5	132.5	276.1 -267.3	271.4	267.7
Trade	– 24.4– – 22.8	-23.6	-26.9				-35.3- -29.7	-31.0	-44.4			
Other African LDCs:												
Production	47.1– 50.0	48.6	45.5	150.7 -160.2	155.6	145.5	61.3- 63.7	63.1	61.5	197.1 -204.9	203.0	197.8
Consumption	51.9– 51.5	51.5	48.5	161.2- 160.0	160.0	150.5	63.3- 63.0	60.7	62.0	196.4 -196.4	189.1	193.2
Trade	– 4.8– – 1.5	– 2.9	– 3.0				- 2 . 0 - + . 7	+ 2.4	– .5			
South Asia:												
Production	184.2– 186.0	190.0	178.6	154.0-155.5	158.9	149.3	265.0- 259.0	269.0	271.0	221,6-216.8	225.2	226.9
Consumption	199.7– 199.0	200.0	186.3	158.7- 158.2	159.0	148,0	284.3- 275.7	290.7	293.9	226.2 -219.4	231.3	233.9
Trade	– 15.5– – 13.0	-10.0	– 7.7				-19.3- -16.7	-21.7	-22.9			
Southeast Asia:												
Production	38.3– 41.4	38.6	39.6	179.1 -194.3	180.6	185.5	62.0- 65.0	62.6	64.1	295.3 -310.0	298.3	305.6
Consumption	30.5– 30.5	29.9	30.7	168.0- 168.0	164.5	169.1	47.9- 47.0	48.0	49.9	268.8 -263.6	257.8	280.4
Trade	+ 7.8– + 10.9	+ 8.7	+ 8.9				+ 14.1- + 18.0	+ 16.6	+ 14.2			
East Asia:												
Production	44.9– 44.6	46.5	43.2	155.8- 154.7	161.4	149.7	71.9- 73.0	72.4	72.2	251.4 -255.3	253.1	252.4
Consumption	63.8– 63.5	63.7	61.3	173.1 -172.3	172.9	166.2	98.0- 97.0	95.0	100.5	267.7 -264.9	259.4	274.6
Trade	– 18.9– – 18.9	-17.2	– 18.1				-26.1- -24.0	-22.6	-26.3			
World:												
Production	1,608.2– 1,583.6	1,642.9	1,540.7	141.5 -140.5	144.5	137.0	2,196,7 -2,141.7	2,233.0	2,119.6	194.0 -191.0	198.0	191.5
Consumption	1,608.2– 1,583.6	1,642.9	1,540.7	141.5 -140.5	144.5	137.0	2,196 .7-2,141.7	2,233.0	2,119.6	194.0 -191.0	198.0	191.5

NOTE: In trade figures, + indicates export; minus sign indicates import.

SOURCE: The Global 2000 *Report to the President, vol. 2,* pp. 91-92.

to the report, that "[the] agricultural and trade policies of a small number of importers and exporters will play an increasingly dominant role in determining the quantities and prices of food traded on the world market." The United States is projected to play an increasingly dominant role in balancing world supply and demand by expanding or contracting production in order to moderate price fluctuations. *[4]

The Global 2000 environmental projections related to agriculture suggest that food production could fall significantly below the quantities projected by GOL due to soil deterioration, pest- or pathogen-control problems, water shortages caused by deforestation, and unstable supplies of energy-related inputs. U.S. and foreign government policies will play a large role in deciding whether or not environmental problems seriously erode global agricultural production potential. These concerns will probably seem more important to the industrialized nations than to the LDCs, which are more likely to face the pressing problem of expanding production to meet rapidly expanding food needs, often regardless of long-term environmental costs. Model-comparison exercises similarly suggest that if GOL were more integrated—i.e., if it gave greater attention to the interactions between agriculture and other economic sectors or environmental conditions—its results would probably be less optimistic:

> The rising food prices and regional food shortages projected in the agricultural model would be intensified by the fact that agriculture is not the only sector wanting capital to cope with increasing population demands and diminishing returns. Land degradation caused by intense pressure on the land and by pollution would tend to

[14]Ibid., vol. 2, pp. 77-90.

[15]Ibid., vol. 2, p, 89.

Table B-5.–Per Capita Grain and Total Food Production, Consumption and Trade (Alternatives 1, II, Ill) As projected by the GOL Model for Global 2000

	1985						2000					
	Grain (kilograms)			Food (1989-71 = 100)			Grain (kilograms)			Food (1989-71 = 100)		
	I	II	III	I	II	III	I	II	III	I	II	III
Industrializated countries:												
Production	716.9- 883.8	719.2	889.7	112.9-104.5	115.2	105.0	838.5- 769.8	847.5	716.9	128.8-118.4	131.8	108.8
Consumption	613.7- 587.3	858.9	569.4	108.8-104.9	115.2	102.1	735.0- 692.4	798.3	619.2	127.7-121.2	139.1	110.0
Trade	+105.1- +76.5	+62.3	+100.3				+ 103.5- + 77.4	+ 49.2	+ 97.7			
United States:												
Production	1,331.2- 1,301.0	1,324.6	1,322.1	124.8-122.2	124.2	124.0	1,697.4- 1,840.3	1,719.1	1,479.5	158.0-151.1	157.8	137.4
Consumption	923.5- 874.9	1,021.9	629.9	108.5-103.4	118.9	98.7	1,183.3- 1,111.5	1,383.3	917.7	135.9-128.3	154.8	107.9
Trade	+407.7-+428.1	+302.7	+492.2				+514.1-+528.8	+ 355.8	+ 581.8			
Centrally planned countries:												
Production	411.5	452.5	369.6	116.7	127.6	107.2	451.1	489.2	375.3	129.6	135.6	112.8
Consumption	432.5	458.5	400.4	122.4	125.0	115.9	473.9	495.1	398.5	135.6	138.4	119.0
Trade	-21.0	-6.0	-30.8				–22.8	-5.9	-21.2			
Less developed countries:												
Production	182.0- 189.4	190.4	178.3	101.7-106.5	108.7	99.1	195.6- 197.1	210.2	176.6	109.5-110.8	119.5	99.1
Consumption	203.0- 201.6	207.8	191.8	107.7-106.7	110.6	101.8	210.2- 205.5	219.4	189.5	111.0-108.6	116.7	99.9
Trade	-21.0- -12.2	-17.4	-13.5				-14.6- –8.4	-9.2	-12.9			
Latin America:												
Production	247.7- 247.4	264.3	259.6	108.2-118.9	114.9	113.0	305.9- 311.4	348.6	288.0	131.5-133.7	147.6	123.6
Consumption	244.0- 240.8	262.8	234.5	110.9-109.6	118.7	108.9	282.8- 278.1	308.0	243.8	127.1-125.1	138.7	110.8
Trade	+3.7- +33.6	+1.5	+25.1				+23.1- +33.3	+40.6	+42.2			
North Africa/Middle East:												
Production	201.8- 203.9	209.0	188.4	87.2- 88.3	91.0	80.1	218.3- 222.5	239.9	188.6	95.9- 98.2	107.4	80.3
Consumption	289.4- 285.8	295.1	264.1	101.8-100.3	104.2	99.7	301.8- 292.8	318.6	283.7	105.9-102.2	112.9	98.4
Trade	–87.6- –81.9	-88.1	-95.6				-83.6- -70.3	-78.7	-95.0			
OtherAfrican LDCs:												
Production	130.7- 138.7	138.2	125.5	98.1-104.3	102.3	94.0	109.0- 113.2	123.8	108.0	81.2- 84.5	92.7	80.5
Consumption	144.0- 142.9	144.4	133.7	105.0-104.2	105.3	97.3	112.5- 112.0	119.1	108.8	81.3- 80.9	88.3	78.5
Trade	–13.3- -4.2	-8.1	-6.3				-3.6- +1.2	+4.7	–0.8			
South Asia:												
Production	170.0- 171.7	177.1	160.7	104.6-105.6	108.9	98.8	174.0- 170.0	176.1	152.1	107.0-104.6	109.6	93.5
Consumption	184.3- 183.7	188.4	167.7	107.8-107.4	109.0	98.0	186.7- 181.0	192.4	184.9	109.2-105.8	112.5	98.4
Trade	-14.3- –12.0	–9.3	-7.0				–12.7- –11.0	-14.3	-12.8			
SoutheastAsia:												
Production	273.6- 295.8	282.0	276.1	116.3-128.4	120.1	118.4	301.9- 316.5	322.7	282.5	129.2-135.9	138.7	120.4
Consumption	217.9- 217.9	218.5	215.6	108.9-108.9	109.2	107.6	233.2- 228.5	237.1	219.9	117.1-114.6	119.2	110.0
Trade	+55.7- +77.9	+63.6	+62.5				+68.7- +87.5	+85.6	+62.6			
East Asia:												
Production	139.9- 138.9	148.4	131.9	104.6-104.9	111.2	98.5	161.1- 163.5	188.7	140.4	121.1-122.6	126.9	105.0
Consumption	198.8- 197.8	203.3	187.1	116.2-115.6	118.9	109.2	219.5- 217.3	221.3	195.5	128.7-127.3	129.7	114.2
Trade	-58.9- -58.9	–54.9	-55.2				–58.5- –53.8	-52.6	-55.1			
World:												
Production	337.7- 332.6	354.4	315.4	109.5- 108.5	114.0	103.0	352.2- 343.2	373.0	302.0	117.0- 114.5	126.0	104.0
Consumption	337.7- 332.6	354.4	315.4	109.5-108.5	114.0	103.0	352.0- 343.2	373.0	302.0	117.0 -114.5	128.0	104.0

NOTE: In trade figures, + indicates export; minus sign Indicates import.

SOURCE: *The Global 2000 Report* to *the President,* vol 2, pp. 93-94.

make the projection of agricultural output more gloomy.[16]

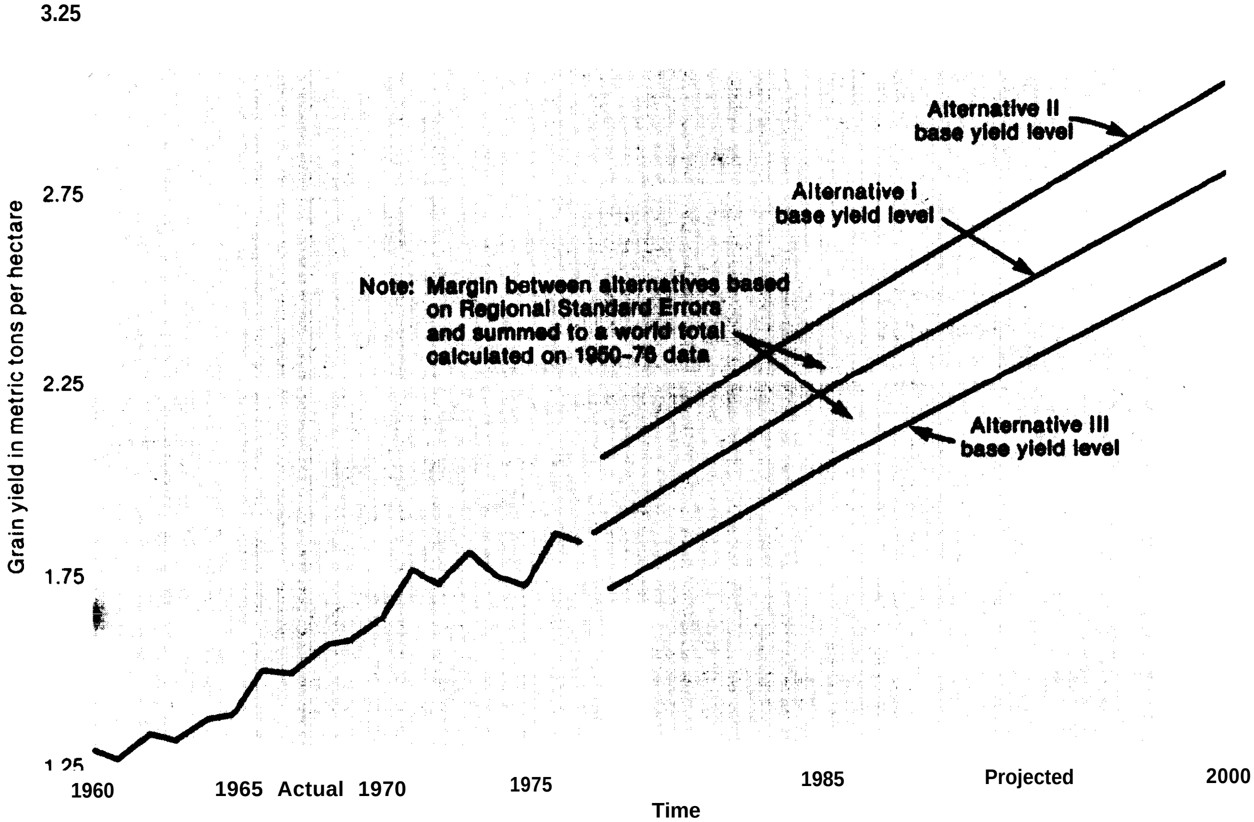
Other Agricultural Projections

One of the most disaggregated and mathematically elegant models of the world food system is the Model of International Relations in Agriculture (MOIRA), commissioned by the Club of Rome in 1973 and carried out by Dutch economists and agronomists with the support of the Government of the Netherlands.[17] It was originally constructed to investigate the consequences for the food system of a doubling of the world's population, and it is explicitly concerned with the problem of world hunger. Its specific purposes are: 1) to describe the global food situation in terms of its underlying causal factors; and 2) to evaluate policy measures, particularly international ones, that might redirect future developments towards improvements in the world food situation. The latter purpose focuses on the growth of food deficits in poor countries and the effect of agricultural and trade policies in the rich countries on the development of food production and consumption in the Third World.

Structurally, MOIRA is similar to GOL in that both of them address only the agricultural sector, leaving critical factors such as population, GNP, and energy inputs as exogenous variables. Both of them rely heavily on traditional economic theories and techniques to represent a world food system controlled by market supply, demand, and prices. They differ, however, in what they disaggregate: whereas GOL disaggregates crops but considers only one class of consumers in each of its 28

[16] Ibid., vol. 2, p. 672.
[17] H. Linnemann et al., *MOIRA—Model of International Relations* m *Agriculture* (Amsterdam: North-Holland Publishing Co., 1979).

Figure B.9.–World Grain Yields, Actual 1960-1976 and Projections to 2000 Under Alternatives 1, Ii, and Ill of GOL for Global 2000



SOURCE: The Global 2000 *Report to the President,* vol. 2, p. 76

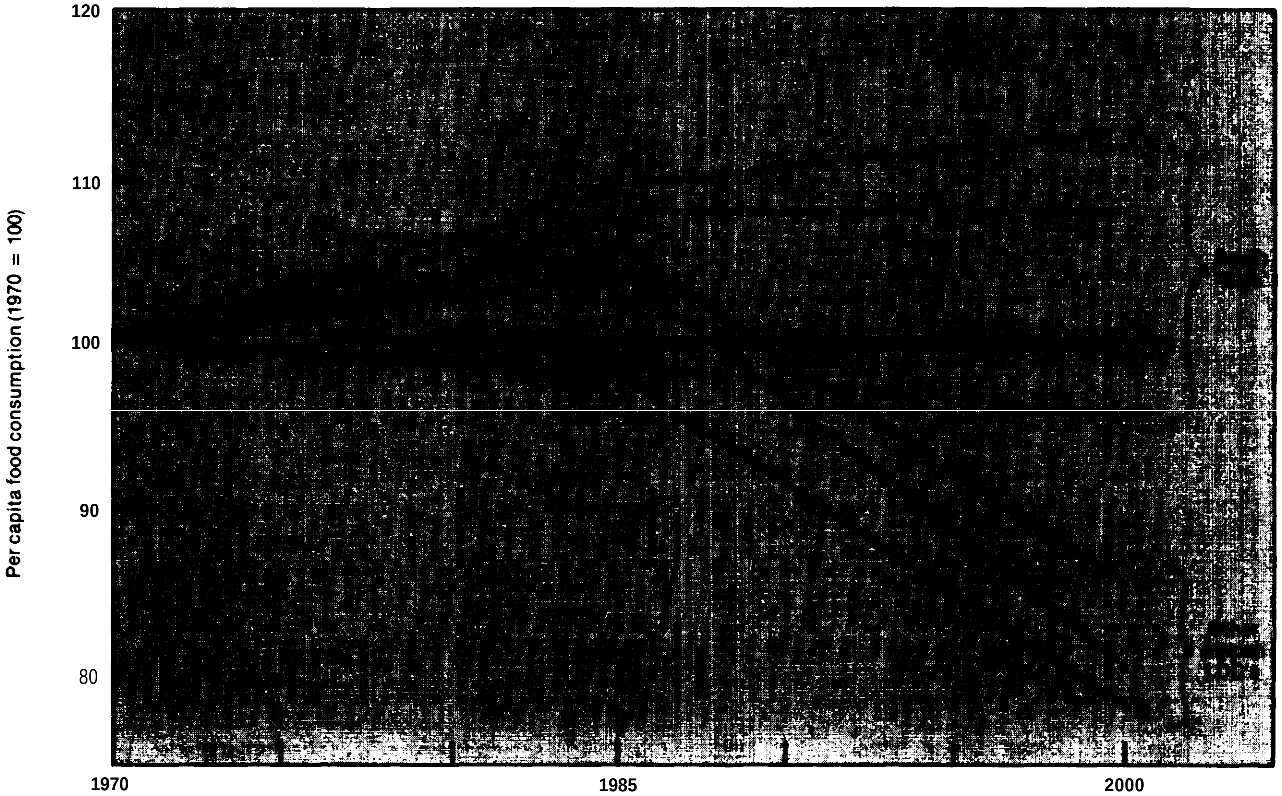
regions, MOIRA considers only one agricultural output—consumable protein—but disaggregates consumers into 12 different income-and~ccupation classes in each of 106 individual nations, which are linked through an equilibrium model of international food trade. This structure allows the model to simulate conflicts of interest between producing and consuming nations or between agricultural and nonagricultural sectors within nations, which in some ways makes it a better tool for food policy analysis.

The model is solved by yearly increments over a 50-year simulation (1960-2010), with the world market assumed to clear each year and the world market price (along with factor costs and technical considerations) assumed to affect the next year's production decisions. Each nation's producers are assumed to operate in such a way as to maximize expected sectoral—not individual—income. National markets buffer themselves from international markets by tariffs or price subsidies that affect the motivations of producers, but a "seepage" effect tends to drive domestic prices toward world prices.

In its normal mode of operation, MOIRA's structure shows demand being steadily increased by population growth and income growth, which leads to higher prices, which in turn stimulate additional supply. Due to the costs of expanding production, however, supply increases more slowly than demand, and low-income consumers who cannot purchase food at the going market price "demand" less food than they actually need to avoid malnutrition. In short, only high prices can increase production, but high food prices relative to consumers' incomes will result in people going hungry. This outcome reveals how, in one critic's view, "this model structure emphasizes the fact that, in today's world —and in the foreseeable future-it is poverty, much more than supply constraints, that is the cause of world hunger."[18]

[18]D. H. Meadows, J. Richardson, and G. Bruckmann (eds.), *Groping in the Dark: The First Decade of Global Modeling* (New York: Wiley, forthcoming), pp. 113-115.

Figure B-10.- Projected Regional Per Capita Food Consumption for South Asia and Sub-Saharan Africa in 1985 and 2000 Under Alternatives i, ii, and iii of GOL for Global 2000
(Index 1969-71 = 100)



NOTE: For illustrative purposes only.

SOURCE: *The Global 2000 Report to the President*, vol. 2, pp. 93-94.

Table B-6.–Projected Net Exporters of Wheat Under Alternative I-A (Medium Growth, Rising Energy Prices) of GOL for Global 2000[a]

	(Million metric tons) 1970		1985		2000		Average annual growth percent	
	Exports	Percent share	Exports	Percent share	Exports	Percent share	1970-85	1985-2000
United States	17,881	39	48,838	58	58,228	57		
Australia-New Zealand	8,300	18	12,165	15	16,084	16	3	2
Argentina,	1,640	4	6,410	8	13,974	14	10	5
Canada	11,750	26	15,288	18	7,311	7	2	-1
South Africa	60	–	839	1	4,108	4	19	11
U.S.S.R.	4,799	11	127	—	1,995	2	-22	20
India	—	—	—	—	186	–	—	—
Euro Six	1,170	3	—	—	—	—	—	—
Total. .,	45,600	101[b]	83,887	100	101,864	100	4	1

[a]These figures are representative of the lowest level of disaggregation within the GOL model and are cited to illuminate the GOL methodology. While Department analysts are reasonably confident of the GOL model's computations at higher levels of aggregation, they would prefer that these more disaggregated projections not be cited as Global 2000 Study projections.
[b]Does not sum to 100 due to rounding.

SOURCE: *The Global 2000 Report to the President*, vol. 2, p. 557.

The standard run of MOIRA, based on a continuation of present trends, assumes moderate population growth, "relatively high" growth in nonagricultural GNP, and no new policy interventions. The results of this scenario shows steady increases in agricultural production (fig. B-1 1) and per capita protein consumption (fig. B-12), along with higher but unstable world market prices (fig. B-13). Nevertheless, there is also a large increase in the number of people below the minimum food standard (fig. B-14). Nutritional gains are greater in the developed regions than in the LDCs, and significantly lower in South Asia than in the LDCs as a whole. The LDCs show a decrease in food self-sufficiency, and North America becomes even more dominant as the leading food exporter. Sensitivity tests conducted to assess the effect of exogenous variables on these results produced the following results:

- lower growth rates in nonagricultural GNP (3.5 rather than 7 percent in the LDCs) reduces demand, prices, and output, resulting in a 35-percent increase in world hunger;
- lower population growth rates (about half the rate of the standard run) also results in lower prices and output, but does produce a 30-percent reduction in world hunger; and
- internal income redistribution outside each country's agricultural sector (gradually reducing present inequities by half their magnitude over the 1975-2010 period) leads to significantly higher effective demand and to price increases 50 percent greater than in the standard run, and, although it increases the food imports of the LDCs, it also reduces world hunger by about 50 percent.

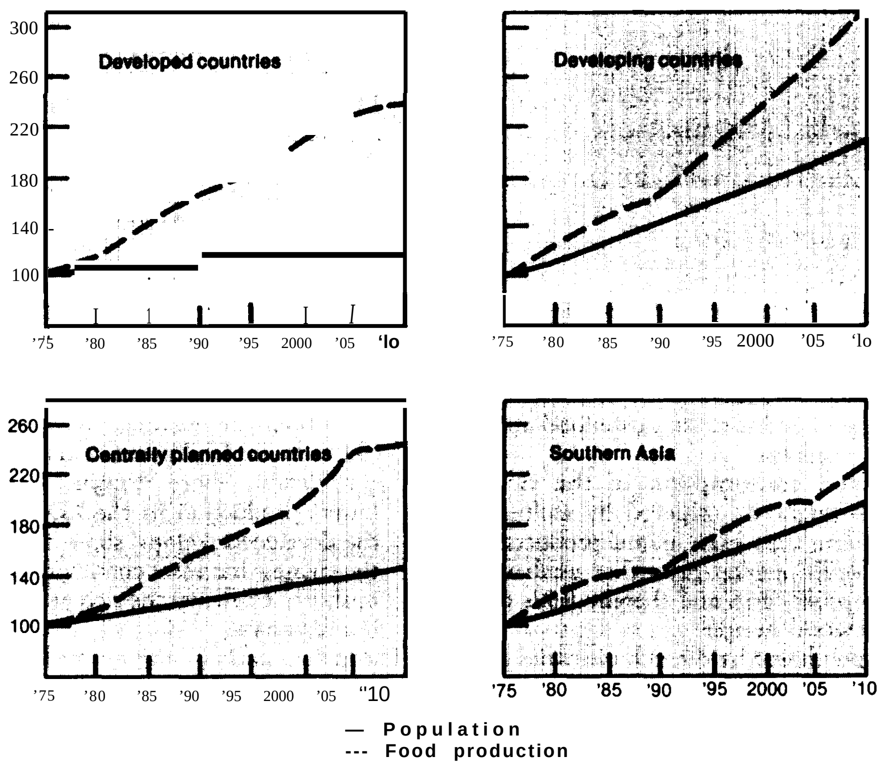
The authors conclude from this last test that "the hunger problem is, to a large extent, a problem of income distribution, " but they are quick to point out the limitations of their model. The general trends it projects are more significant than its precise numerical results, but these sensitivity tests all point to a similar outcome:

> .,. all simulation runs with alternative assumptions regarding exogenous variables have one thing in common: if policies remain unchanged, the number of people who cannot obtain sufficient food will increase.[19]

As a consequence, the authors have used MOIRA extensively for policy testing, with the objective of discov-

[19]Linnemann, et al., op. cit., p. 13.

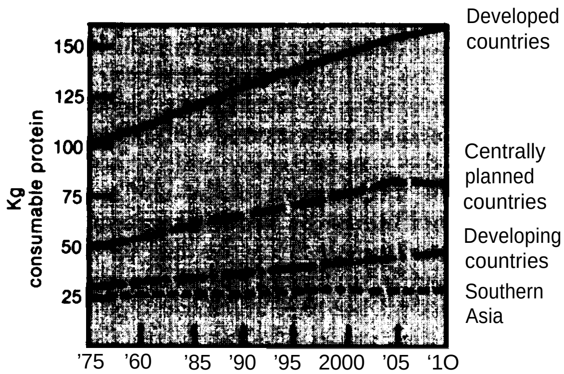
Figure B-n .—Projections of Population and Food Production in MOIRA, Standard Run



NOTE: In all regions production increases faster than population, although in Southern Asia gains are quite modest,

SOURCE: Extracted from *MOIRA*

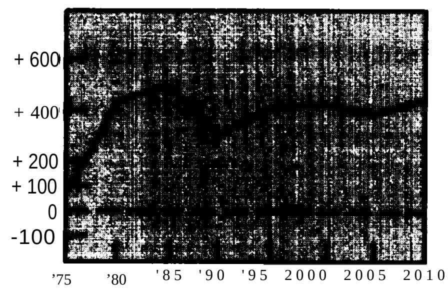
Figure B-12.– Projection of Annual Per Capita Protein Consumption From MOIRA, Standard Run



NOTE: Greatest gains occur in the developed countries. There is a steady gain in developing regions, but Southern Asia shows very little gain.

SOURCE: Extracted from MOIRA, p. 29.

Figure B-13.— Food Prices on World Market in MOIRA, Standard Run

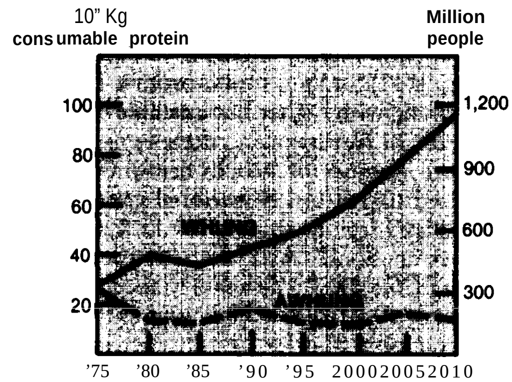


SOURCE: Extracted from *MOIRA,* p. 291.

ering what actions might be taken by the rich nations to contribute effectively to the goal of reducing world hunger. The four basic policy tests involve two measures intended to achieve a redistribution of available food and two measures intended to stimulate food production in developing regions:

- Reduction of food consumption in the rich countries, which might be achieved by shifting consumption patterns (i.e., fewer animal products), results in a low world market price that weakens the incentives to production and thereby leads to increases in total world hunger.
- Food aid, if it is purchased by the rich countries at the prevailing world market price and distributed to those under the food norm in such a way that it does not disturb local markets, is capable of eliminating world hunger almost completely. This optimistic scenario, which requires the developed nations to devote about 0.5 percent of their GNP to food aid, differs from the first in that it raises world market prices, particularly between 1980 and 1990, and thereby stimulates additional production.
- Regulating international food trade, in order to stabilize world market prices at a relatively high level, also proves to be an effective way to stimulate production and improve the food situation in the LDCs, particularly under the assumption of low economic growth outside the agricultural sector. Such a policy might be difficult to implement, however, because it would require the rich nations to create buffer stock and to regulate their imports and exports in order to keep prices at desired levels; under some conditions this might require North America to give up its leading position as a food exporter.
- Liberalizing international food trade, which would require rich countries to cease protecting their domestic markets from world food prices, causes lower food prices and (over the long term) considerably more hunger. Because this policy lowers' production in the LDCs, it also increases the developed regions' share of food exports, with the greatest increases coming from North America; in short, it benefits the rich at the expense of those less fortunate.

Figure B-14.– Total World Hunger (WHUNG) and Hunger in the Agricultural Sector (AWHUNG) in MOIRA, Standard Run



NOTE: Right axis shows number of people with a consumption level below the minimum food standard. Left shows total food deficit in 10 Kg consumable protein.

SOURCE: Extracted from *MOIRA,* p. 291.

The policy package the authors find most effective combines price stabilization and food aid. They conclude that "[as] long as the rich nations are able and willing to provide the funds" there is little potential for conflict between these apparently contradictory objectives. However, they also found that deliberate changes in income distribution in the poorest countries would "remarkably strengthen the positive effect of food aid and world market regulation."[20] This "global food supply policy" would nevertheless require a concerted effort on the part of the rich nations to adapt their domestic production to the international demand and supply situation.

Strengths and Weaknesses of Projection Techniques

Anyone putting an agricultural sector into a global model must arrive at formulations for the determinants of agricultural production (supply) and consumption (demand). What he includes and how he includes it determines the results his model will produce, although his biases may strongly influence the way he interprets these results. For example, all of the models except UNIOWM indicate there will be problems supplying food to at least some of the world's people over the next 20 years. The reason for this finding is fairly straightforward: all of the models except UNIOWM show increasing costs for land development as the amount of undeveloped land decreases, and all except UNIOWM show diminishing returns to agricultural inputs. In short, the models show agricultural problems because they include agricultural limits.

However, their other major similarity–advocacy of drastic social and political change—appears to be something modelers interject into their models rather than something they learn directly from the models. The conclusions drawn from global models often suggest that the only way to avert major catastrophe is to alter some difficult-to-change trend such as fertility, investment rate, or income distribution; but the models themselves are insufficiently detailed to tell what these changes would mean in practice.

Table B-7 compares how the six models treat some of the basic factors influencing agricultural systems, with factors affecting demand on the left, factors affecting supply on the right, and factors affecting both supply and demand in the center. It shows that models are more alike in what they leave out (make exogenous) than in what they include, but even when a variable is endogenous there are differences in how models treat it. All of these differences affect results in some way, although it is sometimes difficult to establish how. For example:

- Differences in aggregation cause large differences in the form of model output, but they frequently have no effect on model behavior other than making results more or less detailed, or more or less difficult to interpret. Experimentation with different levels of aggregation has led many modelers to prefer more aggregated structures, which give nearly identical results at a much lower cost. On the other hand, sometimes disaggregation does matter: if one were to aggregate grains and livestock in GOL, UNIOWM, or any other model that differentiates between agricultural products, one would probably observe a change in the way the model responds to high prices and/or poor harvests.
- Structural differences that have no effect under one set of circumstances may be all-important under another. For example, the soil degradation mechanism in World 3 has almost no effect on the model's standard run, but when nonrenewable resource constraints are removed the resulting pollution causes agricultural yields to plummet, and the system must begin devoting a large part of its industrial output to rescuing the agricultural sector.
- Seemingly different structures can behave similarly, while seemingly similar structures behave very differently. For example, World 3, UNIOWM, and LAWM all lack price mechanisms; however, both the LAWM and World 3 will cause investment to flow in the direction of a sector that shows signs of supply shortfalls, while UNIOWM contains no such mechanism.
- Important structural features may be buried in accounting matrices. For example, a zero entry in an input/output matrix, or an assumption of non-substitutability between two classes of agricultural commodities, could greatly affect intersectoral flows in any of the multicommodity models (GOL, UNIOWM, and WIM).

In short, the way a model's structures affects its results can be complicated, so much so that modelers themselves are often at a loss to explain system behavior. There are, however, some situations in which model behavior is easily traced to model structure, and there are many other situations where this influence is at least a plausible explanation. LAWM's pronounced tendency to rapid urbanization, for instance, results from the fact that its optimization routines are based on statistical research that showed a high correlation between living in cities and life expectancy; LAWM's behavior with regard to housing and education can be explained in the same way. Similarly, the relatively pessimistic projections of GOL and World 3 with respect to food per capita certainly result in part from the fact that neither model includes labor in its agricultural production functions; the relatively optimistic findings of LAWM and MOIRA, on the other hand, probably owe something to their inclusion of labor.

MOIRA assumes that farmers produce the quantity of outputs that will maximize their profits at a given price level for agricultural inputs, which explains why

[20] 1 bLd., p. 329.

Table B-7.—Comparison of Structural Assumptions in Six Global Models

	Demand		Supply and demand			Supply		
Model	Population	Income growth	Intersectoral interaction	Prices	Trade	Constraints	Technology	Environment
worm	Births and deaths endogenous. 4 cohorts, 1 region.	endogenous, driven by supply of capital and inputs.	Agriculture, industry, compete for investment. If one sector fails it brings others down.	Omitted, implicit in links between supply and demand.	Omitted.	Diminishing returns for land investment and. agricultural inputs, depletable mineral resources.	embodied in capital stock, properties may be changed by policy, no automatic progress in disembodied technology	soil delerloration and pollution affect yields.
WIM	Births and deaths semi-endogenous, 10+ regions, 85 cohorts.	Endogenous, driven by supply of capital and inputs.	Multisectoral, Input-output with detail on energy and machinery, energy shortage reduces production, agricultural development needs industrial growth.	Explicit, endogenous, by sector.	Food and other imports constrained by balance of payments.	Diminishing returns on land investment and agricultural inputs, depletable energy resources.	Embodied in capital stocks, investment shifted by price and profit criteria, no automatic progress in disembodied technology.	Omitted.
UNIOWM	Exogenous, 15 regions.	Exogenous, fast enough to meet UN targets.	40 sector input-output, no intersec. toral competition, just accounting of intersectoral flows.	Exogenous, by sector for all sectors, based on input cost projections.	All sectors, Import substitution exogenously determined.	None, linear returns to inputs.	Exogenous updates of input-output coefficients changes production efficiencies, i.e., automatic disembodied technological progress.	Emissions of pollutants calculated for each sector, no feedback to yields.
MOIRA	Exogenous, 106 nations, 6 rural and 5 urban income groups, urban-rural migration endogenous.	Exogenous.	Nonagricultural growth affects income, hence agricultural demand. Relative income levels in agriculture and nonagriculture affect mlgratlon.	Domestic food prices endogenous, policy controlled, world food price balances supply and demand.	Food only, detailed representation of trade policies, assure. ing policy tries to keep agricultural incomes in line with nonagricultural incomes.	Diminishing returns on land Investment and agricultural inputs.	Embodied shifts through producers investing to maximize profits. Disembodied progress automatic.	Omitted (to be included in MOIRA2)
LAWM	Births and deaths endogenous, 4 regions, maximizes life expectancy.	Endogenous, driven by supply of capital and labor.	5 sectors compete for capital and labor; allocation based on sectoral contribution to basic needs fulfillment. Agriculture needs capital sector inputs.	Omitted,	Unimportant, mostly omitted.	Diminishing returns on land investment and yields.	Disembodied progress automatic, in agriculture 1 percent per year gain in efficiency. I	Omitted.
G2000	Exogenous, 28 regions.	Exogenous.	Sensitive to energy prices, little other interaction; within agriculture, high level of interaction between grain and livestock.	Agriculture, endogenous by commodity; energy, exogenous.	Multicommodity trade in agricultural products, some policy representation particularly for United States.	Apparently linear returns on inputs, no limits.	Disembodied progress automatic, following trends observed in the recent past.	Omitted in GOL, analyzed verbally.

SOURCE: Office of Technology Assessment.

measures that drive up agricultural prices are successful as a means of reducing hunger. However, profit maximization may be a better approximation of the behavior of rich farmers than of poor farmers (who may not be able to borrow funds for expanding production, and who may resist giving up their traditional agricultural practices), and for this reason MOIRA probably overestimates the response to price incentives in the developing countries, thereby underestimating hunger in its rapid-economic-growth scenarios. Finally, as discussed below, the structural decision to make important parts of the system exogenous often results in a model whose reliability and accuracy are heavily dependent on the projections used to drive the model.

Factors Affecting the Reliability and Accuracy of Agricultural Projections

Model Structure and Assumptions

Most global modelers enjoin readers against taking their numerical forecasts as precise estimates, Nonetheless, comparison of numerical results, in conjunction with comparison of structures and assumptions, is a useful means of determining why various global models make the projections they do. Table B-8 compares the projections made by six models for key agricultural variables in 2000, including food production, prices, expansion of cultivated land, and yields. To eliminate differ-

Table B-8.—Comparison of Projected Values of Critical Agricultural Variables in Different Global Models

	Food production	Price increase	Cultivated land		Yield	Global food/capita	Regional food/capital		
World 3	280	Not relevant	130		120	109	Not included		
UNIOWM	285 grain	114	Region	Arable land	Land productivity	158 grain		Calories	Protein
	274 livestock		Developed market:			155 animal products	South Asia	120	127
			North America	111	194		Africa (tropical)	127	140
			Western Europe (high-income)	100	162		Latin America (low income)	125	143
			Japan	100	269		Latin America (high income)	132	148
			Oceania	183	162				
			Centrally planned:						
			Soviet Union	100	215				
			Eastern Europe	100	186				
			Asia (centrally planned)	120	278				
			Developing market:						
			Latin America (medium-income)	166	311				
			Latin America (low-income)	140	328				
			Middle East	126	487				
			Asia (low-income)	113	331				
			Africa (arid)	131	282				
			Africa (tropical)	152	324				
MOIRA	244 high growth	522 high growth	Not documented		Not documented	140 high growth		High	Low
	185 low growth	113 low growth				108 low growth	South Asia	125	75
							Africa (tropical)	164	100
							Latin America	168	117
Global 2000	191 to 201 grain	130 optimistic	104		160 to 190	126 optimistic		High	Low
	191 to 198 food	to 215 pessimistic				104 pessimistic	South Asia	113	96
							Other African LDCs.	86	78
							Latin America	137	111
LAWM			Not documented				Africa	-130	
							Asia	-150	
							Latin America	-120	
WIM			Not documented				South Asia	68	

NOTE: Scaled such that 1970 = 100. (For illustrative purposes only, Some of these numbers have been read off of imprecise plotted output and may err by as much as 5 or 10 percent).

SOURCE: Office of Technology Assessment.

ences in measurement, values for 2000 have been indexed to their values in 1970. Generally, world aggregates are used because the models use very different regional aggregations. It has not been possible to include values for all models, because not all models calculate all variables and model documentation often fails to present needed data. Indeed, lack of information has made it impossible to include either the WIM or the LAWM in most calculations.

Projected food production in 2000 ranges from 185 to 285 percent of 1970 figures, an increase equivalent to average annual compound growth rates varying from 2.0 to 3.5 percent. UNIOWM and World 3 give the highest figures; the MOIRA low-growth scenario and the Global 2000/GOL projections give lowest. Price projections vary far more than supply projections: the MOIRA's high-growth scenario, at one extreme, shows a price increase of over 400 percent (most of which, incidentally, occurs before 1985); on the low side, the MOIRA low-growth scenario and UNIOWM project price increases of below 15 percent. Columns 3 and 4 show how much of the increase in output is attributable to expanded cultivation and how much to increased yields; the figures show that World 3 anticipates land expansion, GOL yield increases, and UNIOWM both.

Finally, columns 5 and 6 show global and selected regional figures for per capita food intake. From the differences between columns 5 and 1, one can infer that global population growth is faster in World 3 than in other models and slower in Global 2000. The regional figures, however, show that there is greater variation in regional projections than global projections, with the most severe problems in South Asia and Tropical Africa. These figures also hint that WIM may be considerably more pessimistic than other global models. It should also be noted, however, that model results are highly dependent on time horizon. If one truncates the World 3 standard run at 2000 its projections look optimistic, and similar results arise from truncating the LAWM standard run for Asia at 2000.

Population, economic growth, and disembodied technological progress are exogenous variables in at least three of the six models (see table B-7). All of these variables have important influence on model results, as do their assumptions about the amount of potentially arable land, the cost of developing that land, and the cost of other inputs such as fertilizer, irrigation, and farm machinery. Vital though these factors are to accuracy and reliability, however, there is little agreement among the models on what values they should be assigned. In some cases this disagreement cannot be resolved because of a lack of statistical evidence or theoretical understanding.

Disembodied Technological Progress

It has become conventional for economists to identify that fraction of income growth (or input cost reduction) that cannot be statistically ascribed to increases in labor, capital, or other inputs as "disembodied technological progress," and to make projections of economic growth under the assumption that rates of technological progress observed in the recent past will continue in the future. This amounts to an assumption that productivity will increase automatically. In most such formulations, the productive contribution of technological progress is very significant: rates above 1 percent per year are common, and it is not uncommon for improved technology to appear to contribute more to economic growth than either labor or capital.

Formulations of this type have been employed in the agricultural sectors of LAWM, UNIOWM, GOL, and MOIRA, but not in World 3 or in some versions of WIM. The specific rates of technological progress assumed in various global models are generally not reported in model documentation, however: LAWM assumes a 1.0-percent annual growth in agricultural productivity, 1.5 percent for capital goods, and rates of either 0.5 or 1.0 percent for other sectors; but analogous figures for UNIOWM, GOL, and MOIRA are not available, Nevertheless, testing shows that model results are quite sensitive to both the presence and the rates of disembodied technological progress. When technological progress is omitted from LAWM, for example, Africa joins Asia in being forced against its land constraints and facing economic collapse. On the other hand, if sufficiently strong assumptions about technological progress are introduced into World 3, the overshoot-and-collapse mode can be eliminated from the model altogether.[21] It should be added, however, that nobody has a very good understanding of technological change; its exclusion or inclusion in global models therefore stems ultimately from hunches, beliefs, and values—not from scientific understanding.

Population

Population growth is exogenous in UNIOWM, GOL, and MOIRA. UNIOWM assumes somewhat higher population growth rates than the two other models, so its optimistic projections of food per capita cannot be ascribed to low population growth rates. MOIRA, on the other hand, assumes rapidly declining rates of population growth, especially for countries whose 1970 growth rates were high, and this may contribute to MOIRA'S tendency to become more stable in the last decades of simulation than it is in the first decades. GOL assumes significantly lower population growth rates in the industrialized countries than those projected by the Census Bureau (see app. A). Better linkage in Global 2000 might thus have resulted in less optimistic food trade projections.

Economic Growth

The right side of table B-7 shows the rates of economic growth projected as exogenous drives for the UNIOWM, GOL, and MOIRA. In all three models these projections are used (in combination with the demographic projections) to project income per capita, which in turn is used in projecting demand for agricultural products. The standard runs of UNIOWM and MOIRA assume rapid economic growth in the developing countries (7.2 percent and 7.6 percent per year, respectively). This leads to rapid increases in agricultural demand, due to the fact that demand for food in poor countries is quite income elastic. In UNIOWM, increased demand causes increased production directly, while in MOIRA it causes price increases, which in turn stimulate increased production. When lower rates of economic growth are assumed in MOIRA, prices and production stay low and the food situation improves less rapidly (it even deteriorates, in South Asia). The Global 2000 income growth projections are generally lower, particularly for non-OPEC developing countries, which undoubtedly contributes to the fact that GOL projections of food availability in the LDCs are much more pessimistic than analagous projections in the UNIOWM and MOIRA,

Potential Agricultural Land

MOIRA, World 3, and WIM all use formulations in which the costs of further increases in land development are dependent on the amount of land already under cultivation. A prodigious amount of work went into estimating, these relationships for MOIRA, including derivations of absolute maximum dry-matter production potential based on FAO soil maps and plant physiology models.[22] The figures used in World 3 derive from the President's Science Advisory Committee (PSAC) report, The World Food Problem (1967), and are likewise based on detailed studies of soil maps and climatological data. The derivation of the figures used in WIM has not been documented.

[21] H. S. D. Cole, op. cit., p. 64.

[22] Linnemann, et al., op. cit., pp. 19-74

A comparison of the values used in these three models shows that differences between MOIRA and the PSAC/World 3 are relatively minor–PSAC gives South America somewhat more agricultural land, North America slightly less, and Europe quite a bit less, The WIM estimates, however, proved to be markedly lower for all regions except Western Europe, and WIM's estimate of the world's total potentially arable land are only about 70 percent of the MOIRA figures and about 76 percent of those used in World 3. WIM's relatively pessimistic assumptions about land availability, particularly in the developing regions, undoubtedly contributes to its dire predictions of impending famine. However, as shown in sensitivity tests of the World 3 agriculture sector, an increase in potentially available land of 30 percent or more does not change the net outcome of the model—it merely postpones by a few years the date at which scarcity becomes acute.[23]

[23] J. Randers and E. K. O. Zahn, "The Agricultural Sector," in *Dynamics of Growth m a Finite World*, D. Meadows, et al. (eds.) (Cambridge, Mass.. M.I.T. Press, 1974), pp. 339-348.

Other Factors Affecting Reliability and Accuracy

Global agricultural data are often poor, and all models necessarily contain a lot of guesswork. For example, no one has very many or very good economic data on China, nor are there reliable data on the soils (and hence the agricultural potential and costs of agricultural development) in Amazonia. In addition, agriculture will undoubtedly be affected in the coming decades by several trends for which no global model accounts. None of these six models accounts for potential competition between the agriculture and energy sectors for water or land. None takes the global monetary system into account. None looks at the effects of climatic change or increased levels of atmospheric carbon dioxide. Nor does any of them examine the agricultural consequences of unusally bad weather or a serious destabilization of oil and gas supplies.

APPENDIX C

Energy Projections

Introduction

The future availability and price of natural resources are crucial variables in long-range projections of world economic development. Energy supply and demand in particular affect not only industrial production but also agriculture, transportation, and general living conditions. As a result, the findings and conclusions of these five global modeling studies are significantly influenced by their treatment of the global energy system and their assumptions about future energy trends. Some of the models do not address energy specifically, or in detail, and others merely assume that energy will not be a constraint within their restricted time horizons.

In general, those models that include a finite resource stock tend to show that depletion will raise prices, slow production, and dampen global economic growth; in short, resource constraints make them susceptible to economic collapse. Even the most optimistic findings, however, suggest that the world faces a difficult transition away from dependence on oil. Coal, nuclear, and solar power are offered as the principal alternatives for the future energy system. The accuracy and reliability of these projections are also influenced by their assumptions about population and economic growth, potential technological progress in extraction and conservation, the potential for substitution and alternative sources, and the future political and economic behavior of both producers and consumers.

Purposes, Structures, and Findings

World 3

Although *The Limits to Growth* is sometimes said to have "predicted" the energy crisis of the 1970's, the World 3 model itself does not specifically address future trends in energy supply and demand. The purpose of the model is to describe the world as a general system rather than to predict its parts in detail, so energy resources—petroleum, natural gas, and coal—are lumped together with 16 other raw materials (primarily metals) in a single category called "nonrenewable resources." The authors cite U.S. Government estimates showing total reserves of individual resources ranging from 7 to 5,100 years, but they assume that, on average, there are about 250 years worth of nonrenewable resources at 1970 consumption levels. They also assume, however, that the quantity of resources consumed per capita is a fixed function of average income per capita, and that continued population and economic growth will lead to a 4-percent growth rate in total world resource consumption. Consequently, this 250-year reserve would be completely used up by about 2040 if growth continues unabated. In addition, the model assumes that the cost of obtaining resources will rise dramatically once 50 percent of the reserves have been depleted, due to declining resource quality and increasing transportation costs.

The standard run of World 3 demonstrates the consequences of this combination of assumptions for the behavior of the nonrenewable resource sector and for the entire world system (fig. C-1). Rising population, combined with rising industrial production per capita, results in the rapid depletion of resources and an equally rapid increase in the costs of obtaining the resources. As more and more capital is diverted from agricultural and industrial production to the obtaining of raw materials, per capita food and industrial output alike begin to decline. This leads eventually to mass starvation and the collapse of the world economic system,

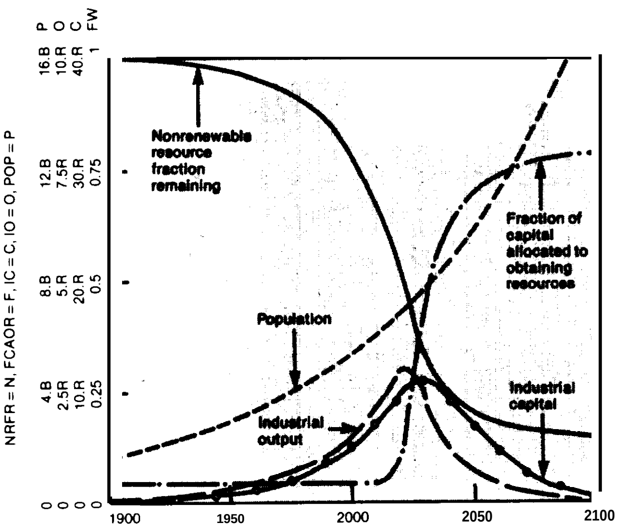
Sensitivity tests conducted by the authors of World 3 indicate that the general behavior of the nonrenewable resource sector and of the integrated world system are not particularly sensitive to their assumptions about resource reserves, consumption rates, or extraction costs.

- If reserves are set at twice their initial value, the collapse is delayed by only 15 years (fig. C-2).
- A tenfold increase in initial reserves will eliminate resources as a constraint to growth—at least before 2 100—but the general behavior of the world system remains unchanged. In this case, persistent pollution causes a decline in production followed by starvation and a decline in population (fig. C-3).
- Improved extraction technologies, by reducing the short-term cost of obtaining virgin materials, would eliminate the economic incentives for conservation and substitution. These technologies could delay the collapse a few years, but they would cause a faster depletion of resources and a sharper eventual decline in industrial output (fig. C-4).
- Improved conservation technologies, sufficient to reduce per capita consumption by a factor of four, allow much higher industrial output and postpones its decline for about 40 years, but they cannot prevent eventual collapse (fig. C-5).

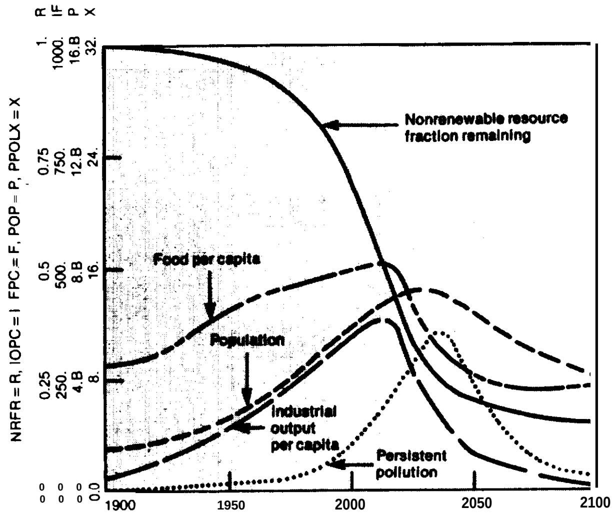
The only model run that succeeds in postponing the collapse beyond 2100 is based on the combination of

[1] The following material is based in part on the draft working paper, "The Role of Energy in the Global System)" by Paul Werbos, Office of Energy Information Validation, Energy Information Administration, U.S. Department of Energy.

Figure C-1.—Impact of Resource Depletion on the Nonrenewable Resource Sector and Integrated Model, World 3 Standard Run



Run 5-1: standard run for the nonrenewable resource sector.

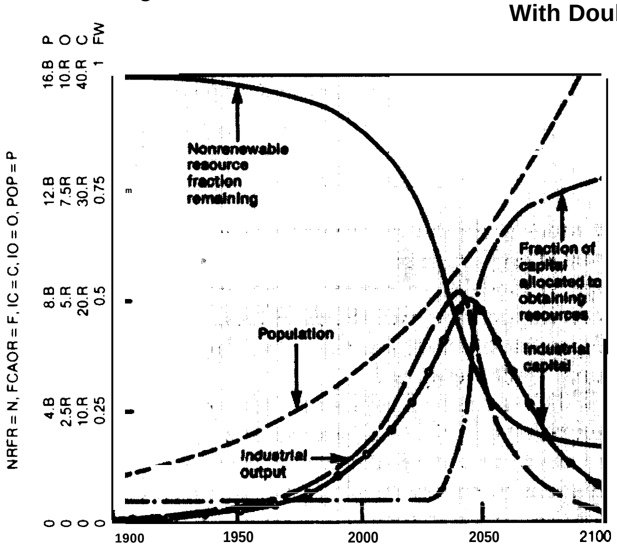


Run 7-6A: World 3 reference run.

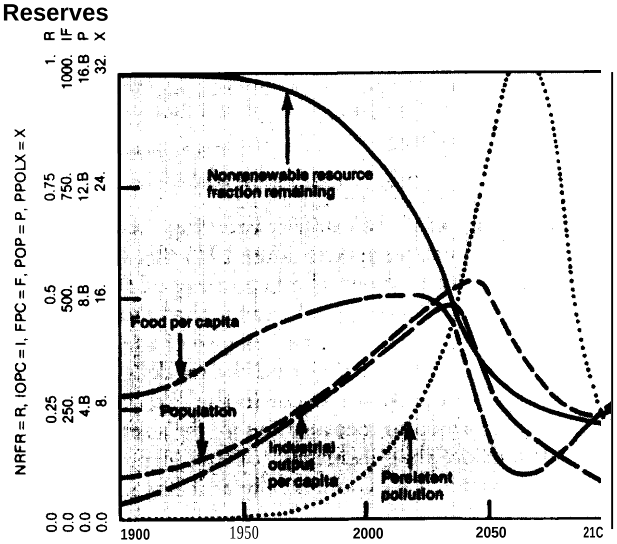
This is the World 3 reference run, to be compared with the sensitivity and policy tests that follow. Both population POP and industrial output per capita IOPC grow beyond sustainable levels and subsequently decline. The cause of their decline is traceable to the depletion of nonrenewable resources.

SOURCE: *Dynamics of Growth in a Finite World.*

Figure C-2.— Behavior of the Nonrenewable Resource Sector and Integrated World 3 Model With Doubled Reserves



Run 5-2: behavior of the sector with double the initial value of nonrenewable resources.

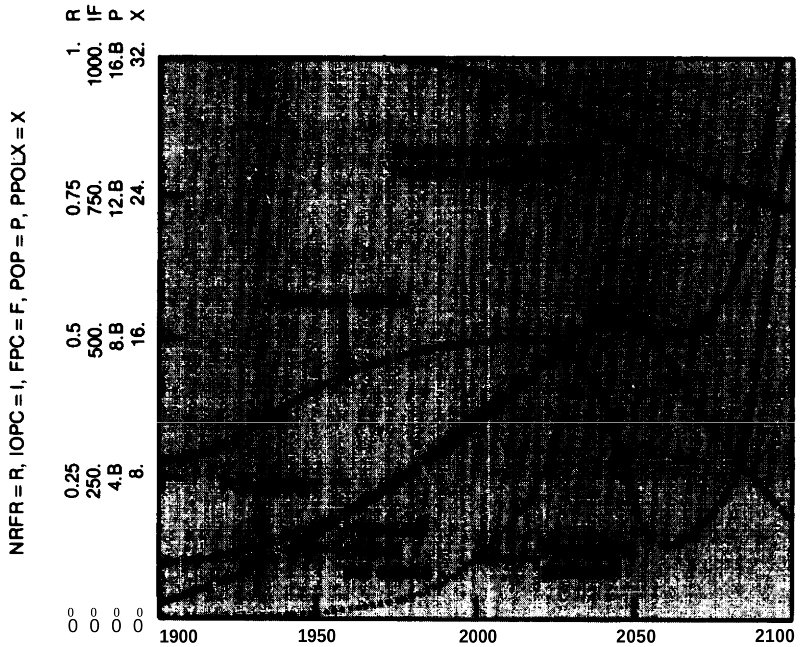


Run 7-7: sensitivity of the initial value of nonrenewable resources to a doubling of NRI.

To test the sensitivity of the reference run to an error in the estimate of initial nonrenewable resources, NRI is doubled. As a result, industrialization continues for an additional 15 years until growth is again halted by the effects of resource depletion.

SOURCE: *Dynamics of Growth in a Finite World.*

Figure C-3.—Behavior of the World 3 Model When Initial Resource Reserves Are increased Tenfold



Run 7-8: sensitivity of the initial value of nonrenewable resources to a tenfold increase in NRI.

The initial value of nonrenewable resources NRI is increased by a factor of 10, to a value well outside its most likely range. Under this optimistic assumption, the effects of nonrenewable resource depletion are no longer a constraint to growth. Note that there is no dynamic difference in this run between setting resources at 10 times their reference value or assuming an infinite value of resources. However, population and capital continue to grow until constrained by the rising level of pollution.

SOURCE: *Dynamics of Growth in* a *Finite World.*

cost-reducing and resource-conserving technologies with zero population growth after 1975 (fig. C-6). Even this run, however, shows the beginning of the characteristic rise in the amount of capital that must be allocated to obtain resources—the collapse of the economic system, although delayed beyond the model's time horizon, will undoubtedly still occur in the 22d century. No test was performed to measure the model's sensitivity to the assumption that industrial output per capita will continue to increase exponentially as it has in the past.

World Integrated Model (WIM)

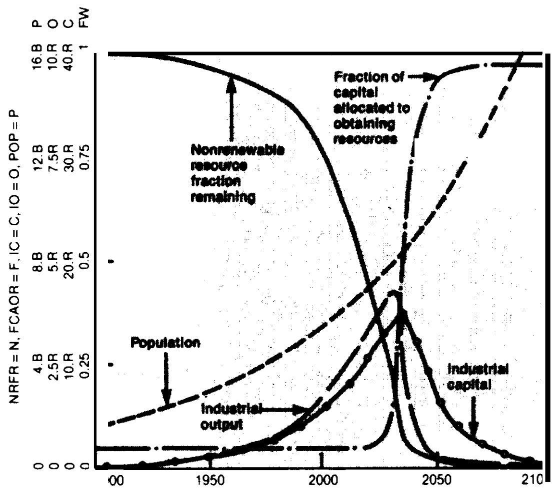
WIM is both more detailed and more flexible in its treatment of energy resources than World 3, and it has been used extensively for testing alternative energy futures. WIM specifically represents both the supply and the demand for five different energy sources—oil, gas, coal, hydroelectric, and nuclear—within each of its 10 or more geographical regions.[2] The model also represents energy trade between regions, a significant advantage in modeling a world system where some 110 nations import over two-thirds of their energy needs and 90 percent of all oil supplies move through the international trade network. J

WIM's structural equations reflect the assumption that rising oil prices will lead to both conservation and the development of alternative sources of energy. Investment in energy development is partially controlled by price, which in turn is determined by supply and demand. The model also assumes that oil will cover a declining portion of total world energy demand after

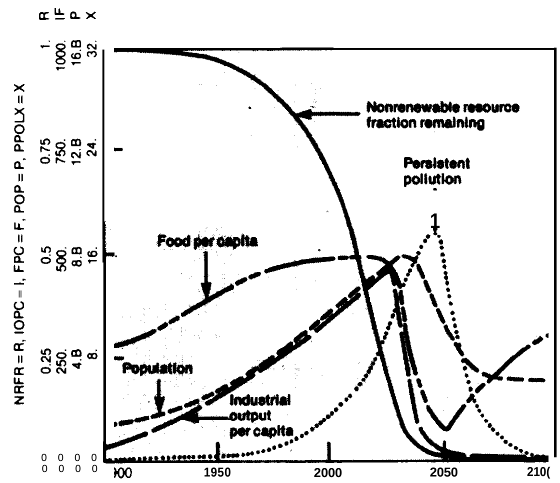
[2]The fifth category, "nuclear energy," also includes solar energy and other capital-intensive alternatives. Source: Command and Control Technical Center (CCTC), Wodd Integrated *Model Multilevel Hierarchical* Theoretic Concepts, CCTC Technical Memorandum TM 197-79 (Washington, D. C.: U.S. Defense Communications Agency, June 15, 1979), pp. 2-17.

[3]M. D. Mesarovic and E. Pestel, Mankind at *the Turning Point* (New York: Dutton, 1974), p. 180.

Figure C-4.– Impact of Cost-Reducing Extraction Technologies on the Nonrenewable Resource Sector and Integrated World 3-Model



Run 5-3: the **effects of cost. reducing technologies on the behavior of the nonrenewable resource sector**

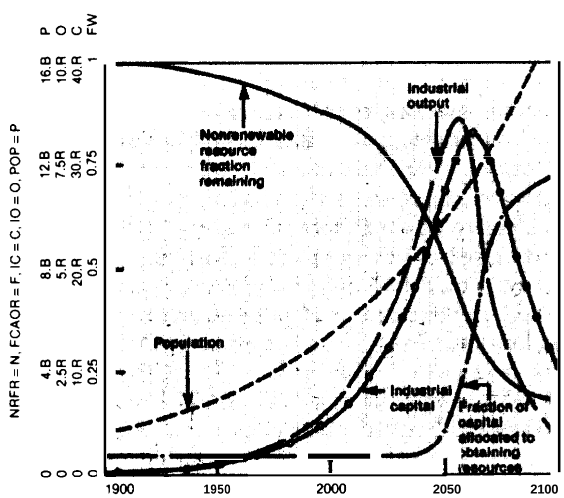


Run 7-12: improved resource exploration and extraction technologies.

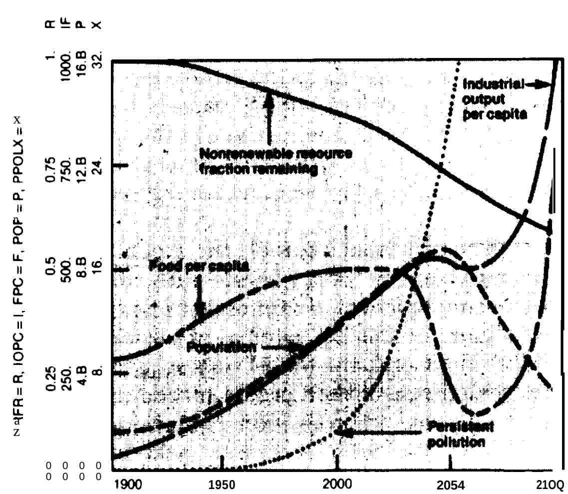
The implementation of improved resource exploration and extraction technologies in 1975 is modeled by lowering the capital cost of obtaining resources for Industrial production. This policy allows industrial production to continue growing for a few more years than in the reference run, but it is ineffective in avoiding the effects of resource depletion.

SOURCE: *Dynamics of Growth in a Finite World.*

Figure C-5.–impact of Resource. Conserving Technologies on the Nonrenewable Resource Sector and Integrated World 3 Model



Run 5-4: the effects of resource-conserving technologies on the behavior of the nonrenewable resource sector.

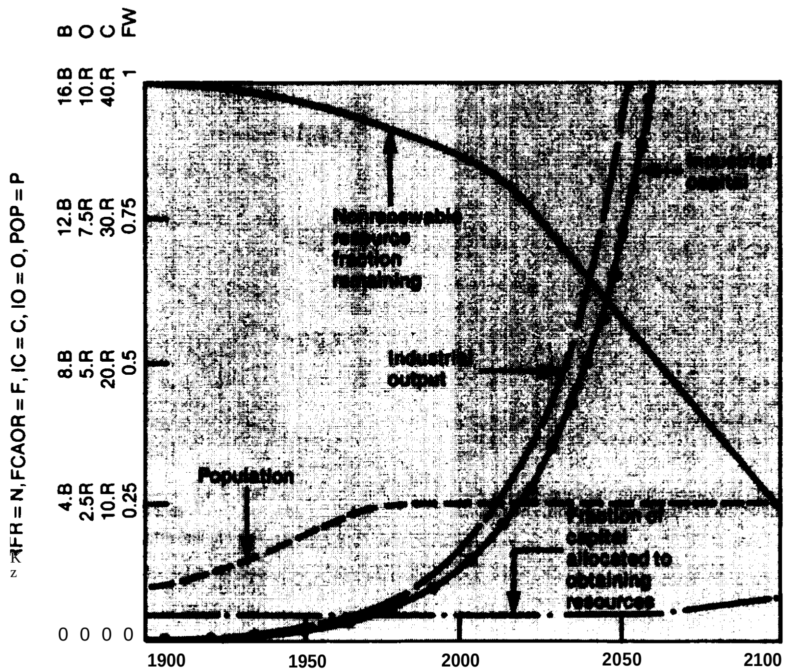


Run 7-13: recycling technologies.

The advances in resource exploration and extraction technologies of Run 7-12 are supplemented by an improvement in recycling technologies that reduces per **capita resource usage by a factor of eight in 1975. That policy removes the constraining effects of resource depletion and allows population and capital growth to continue until checked by persistent pollution**

SOURCE: *Dynamics of Growth in a Finite World.*

Figure C-6.—Combined Impacts of Zero Population Growth, Resource Conservation, and Improved Extraction Technologies on the Behavior of the World 3 Nonrenewable Resource Sector



Run 5-5: the effects of zero population growth and advanced technological policies on the behavior of the nonrenewable resource sector.

SOURCE: Dynamics of *Growth in a Finitefe World.*

1990, and that substitution between energy sources will be based largely on cross-price elasticities, Consequently, although oil and oil substitutes are the most binding resources in WIM, energy supply appears to be constrained less by absolute scarcity than by the speed with which substitutes can be developed—energy is an economic and engineering problem, rather than a physical one.[4]

For use as a policymaking tool, the model provides "scenario variables" or "policy levers" with which users can test the consequences of nonmarket pricing behavior by producers or shifting patterns of substitution by consumers.[5] In general, the model runs suggest that cooperation would benefit both producers and consumers and would also ease the transition away from oil, and that continued long-term economic growth may be possible under either of two alternatives: the rapid and widespread deployment of breeder reactors; or the construction of vast "solar farms" and hydrogen plants in the deserts of the Middle East.

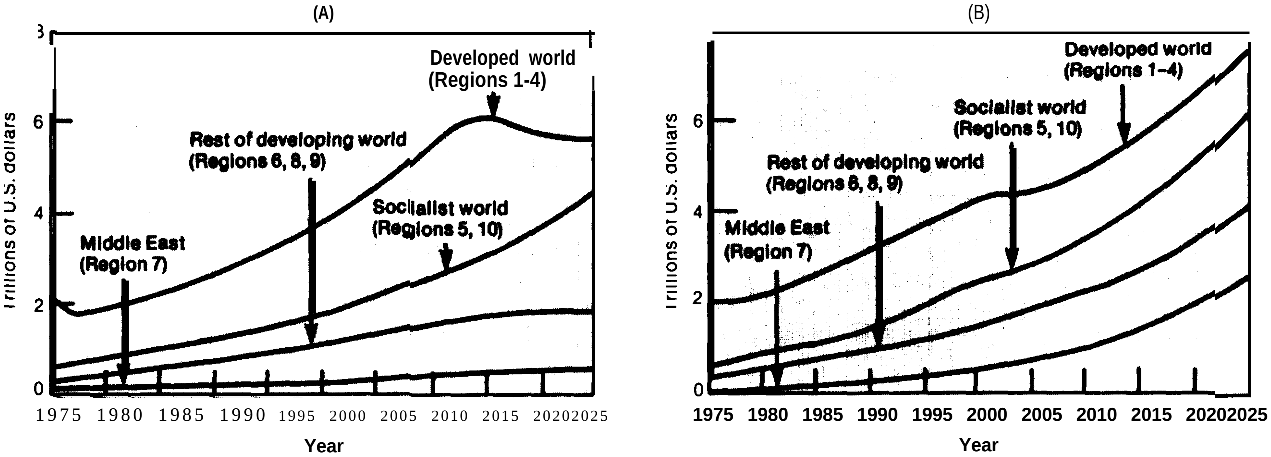
The world oil crisis is a major focus of the many scenarios reported in Mankind at the Turning Point. In the first pair of computer runs, the model was used to demonstrate the long-term economic benefits of an "optimal" oil pricing policy (fig. C-7). Continuation of low oil prices would encourage overexploitation and rapid depletion, discourage the development of substitutes, and lead to major dislocations in the developed regions when reserves are exhausted. Both exporters and importers would fare better under an "optimal price scenario, " in which the real price of oil rises 3 percent annually until it reaches an optimal level (about 50 percent above the initial price of $13.50/barrel, as determined in a separate analysis), at which level it stabilizes thereafter. Optimal oil pricing is assumed in a second set of computer runs that indicates that both exporters and the developed regions benefit under scenarios in which the flow of oil from the Middle East is unimpeded and international energy trade is "governed solely by the economic forces without undue interference from the political level" (fig. C-8).[6] All of these runs, however, project a transient world oil deficit between

[4] P. VanderWerf, "Energy, " in The *Global* 2000 Report to the *President* (Washington, D. C.: Council on Environmental Quality and Department of State, 1980), vol. 2, p. 618.

[5] CCTC, op. cit., pp. 2-17.

[6] Mesarovic and Pestel, op. cit., p. 112.

Figure C-7.—Comparison of Long-Term World Development for World integrated Model "Fixed Low Oil Price" Scenario and World integrated Model "Optimal Oil Price" Scenario



Cheap energy in the form of oil has been a prime fuel for the unprecedented growth of the world economy in the 1950's and 1960's. The dramatic increase in oil prices in **1973 was viewed as a catastrophe. However, computer analysis of our world system model indicates that the continuation of what amounts to overexploitation of oil, spurred by an unreasonably low price, would lead to major dislocations because of the exhaustion of reserves and the lack of motivation to develop substitutes in time. Pursuance of short term objectives would lead to major dislocations in the long run (see A). A much more beneficial development for all concerned results from the "optimal price scenario" in which the price is gradually increased up to the "optimum" level. Such a policy would bring in the substitutes in a more regular fashion while prolonging the reserves. Both exporting and importing regions would fare better (see B). it is only by taking a global and long term view that such a course of development, most beneficial to all concerned, can be identified.**

SOURCE: *Mankind at the Turning Point.*

1997 and 2002 and a severe, persistent deficit beginning around 2020; substitutes or alternative sources would be necessary after that date.

One possible energy future, based on nuclear power, has been proposed by some technological optimists. Tests using the WIM "fast-nuclear scenario" raise questions about the short-term feasibility and long-term consequences of this alternative. After testing short-term scenarios based on Herman Kahn's The Next Two Hundred Years, the authors conclude that:

> It is impossible to design any energy program in Western Europe or Japan which could, over a ten-year period, reduce energy demand and increase production of energy from non-petroleum sources sufficiently to compensate for the loss of the Persian Gulf by 1987. The Hudson report statement regarding the ease of adjustment to a quick disappearance of oil reserves is therefore erroneous. [7]

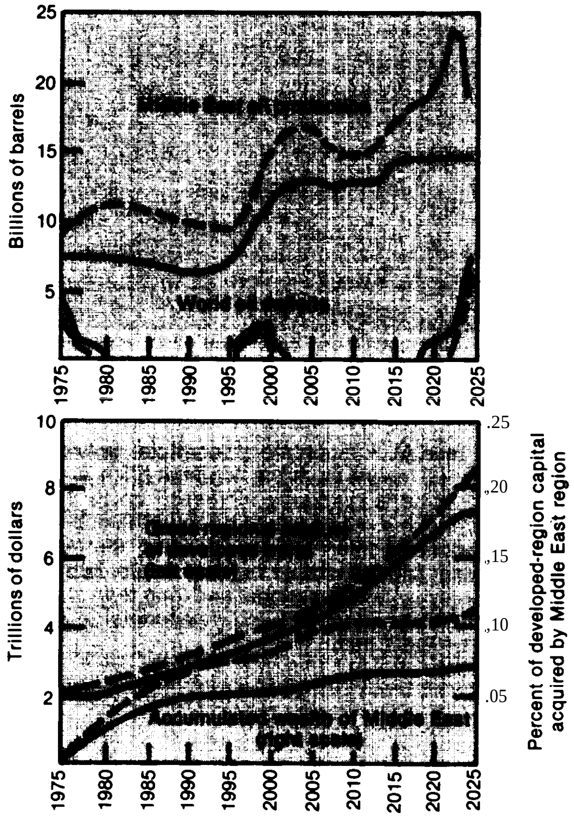
Other WIM tests indicate that the longer term feasibility of the nuclear option is just as questionable. The U.S. Atomic Energy Commission estimated in the early 1970's that nuclear energy would provide 30 percent of the developed world's energy needs by 2000, based on higher demand growth than is now expected. By extrapolating from this figure, the authors found that by 2025 nuclear power would have to provide 60 percent and by 2075 almost 100 percent of all energy needs (see fig. C-9). The social, economic, and security impacts of such a course would be enormous: sole reliance on fission nuclear power would require 24,000 fast-breeder reactors worldwide by 2075, which in turn would require the construction of 4 reactors per week for a century and the eventual construction of about 2 reactors per day just to replace reactors that have reached the end of their 30-year lifespans, at a cost of $2 trillion per year for replacements alone (see fig. C-lO).[8] This scenario would also require the energy sector to process and transport 33 million pounds of plutonium each year; only 10 pounds of this element are needed to construct a nuclear bomb.

Mankind at the Turning Point concludes that an energy future based on nuclear power would be a "Faustian bargain," but this conclusion involves several important assumptions. For one thing, fusion as well as fission could provide the growing nuclear share of energy

[7] B. B. Hughes and M.D. Mesarovic, "Testing the Hudson Institute Scenarios" (Washington, D. C.: U.S. Association for the Club of Rome, September 1979), mimeograph, p. 22.

[8] Mesarovic and Pestel, op. cit., pp. 132-1 M

Figure C-8.—Comparison of Middle East Oii Production, World Oil Deficits, Developed=Worid Gross Regional Product. and Middle East Accumulated ‘Wealth Under Two World integrated Model Scenarios



Solid line: Middle East withholds oil, Imposes ultimate ceiling of 14 billion bbl/yr.
Dotted line: Production and trade governed solely by economic factors.

SOURCE: *Mankind at the Turning Point,*

supply, although fusion power on such a scale would involve similar financial and engineering problems and (at present) even greater technical problems. Another significant factor is the assumed rate of growth for energy demand, which seems unrealistically high in view of subsequent events; in updated projections, higher energy prices and slower demand growth would make the nuclear share—whether fission or fusion-substantially smaller. The authors prefer an energy future that places mid-term reliance on coal and coal-derived synfuels, combined with long-term development of huge “solar energy farms” in the present oil-producing regions. This alternative has not been tested with the model, but it too would involve massive capital and engineering requirements, even with slower energy demand growth. Because of its technical uncertainties (see below), and because it is not based on explicit analysis with WIM, this solar alternative remains speculative.

Latin American World Model (LAWM)

LAWM assumes the nuclear-energy future that WIM rejects, but unlike the other global models it contains no representation of energy or any other resource. The structure of LAWM is based on the assumption that, “for the foreseeable future, the environment and its natural resources will not impose barriers of absolute physical limits” on the satisfaction of basic human needs.[9] The authors base this assumption on two studies conducted independently of the model itself: a survey of currently known reserves of fossil fuels, which found enough oil and gas to last 100 years, and enough coal to last 400 years, at present consumption levels;[10] and an analysis of future production costs for energy, which found that:

> . . . the so-called energy crisis . . . is of a conjunctural character, such as others of similar importance that occurred in the past. And it may be perceived that the main reactions of the system will be to establish a new equilibrium, which, generally speaking, in the long term will not differ from the previously observed trends. ’[11]

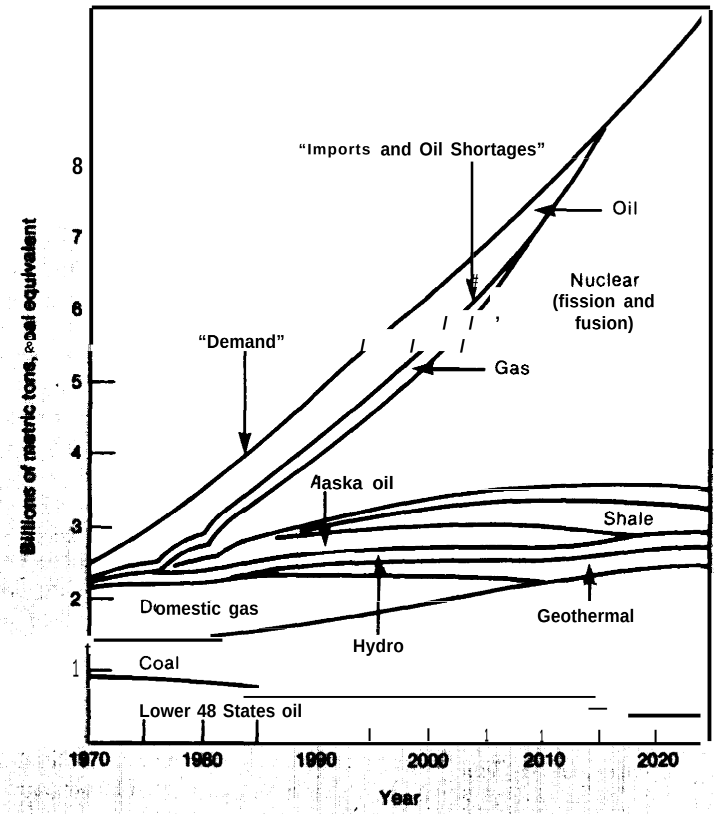
The latter conclusion appears inconsistent with the authors’ own reserve estimates, which represent slightly more oil and gas but considerably less coal than those used in World 3 and WIM, However, the authors assert that “the most important fuels for the future are nuclear fuels.” They cite predictions that nuclear power will generate 50 percent of the world’s electricity by 2000, and, although their own estimate of uranium oxide reserves reflects only 33 years supply even at 1970 levels, they suggest that “a small increase in the price or an advance in technology” will make it economical to extract vast amounts of uranium from granite or seawater.[12] The model itself, however, does not reflect the capital costs or potential technical bottlenecks involved in this nuclear scenario.

United Nations Input-Output World Model (UN IOWM)

The central concern of UNIOWM is to reduce the income gap between the rich and poor nations before the year 2000. In order to determine whether U.N. development targets are consistent with the availability of nonrenewable resources, the model projects the levels of production and world trade in six metals and three en-

[9] A. O. Herrera, et al., Catastrophe or *New Society? A Latin American World Model* (Ottawa: International Development Research Centre, 1976), p. 8.
[10] Ibid., pp. 32-33.
[11] Ibid., p. 34.
[12] Ibid., p. 33.

Figure C:9.- Projected U.S. Energy Supply Distribution for World Integrated Model "Fast-Nuclear" scenario



In the conditions of continued growth, it is important to look over a sufficiently long period of time in the future in order to assess the consequences of selecting one of the available alternatives. The graph in the figure gives projections made by the U.S. Atomic Energy Commission of energy demands in the United States from 1975 up to the year 2000 and how this demand could be met if the decision is made in favor of relying on nuclear energy production. The full impact of such a decision can be seen only when the projection is extended over a sufficiently long period of time. By the year 2025 sole reliance on nuclear power would require more than 50 major nuclear installations, on the average, in every State of the union.

SOURCE: *Mankind at the Turning Point.*

ergy sources (oil, gas, and coal) that would be required to support its relatively high rates of population and economic growth. Its major conclusion:

> The problem of the supply of mineral resources for accelerated development is not a problem of absolute scarcity in the present century but, at worst, a problem of exploiting less productive and more costly deposits . . . and of intensive exploration for new deposits . . . .[13]

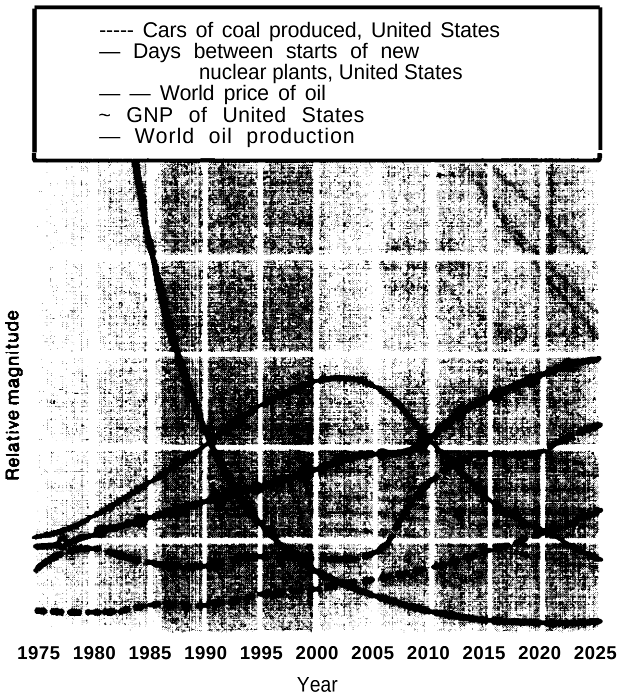
Reserves and prices are determined independently of the model itself, and the amount of each resource required for expansion in each economic sector is adjusted for assumptions about increased efficiency due to technology. Most of these technical assumptions are not reported, although the model does assume 55-percent recycling of all materials, worldwide, by 2000.[14] The model also assumes that all nations will rapidly develop domestic reserves, but that extraction costs will rise as high-grade deposits are exhausted.

The authors project that 77 percent of the world's known petroleum reserves will be depleted by 2000, but their confidence about future energy supplies rests on the world's plentiful reserves of coal, which they "conservatively" estimate at 9 trillion metric tons (roughly the same as World 3). The model assumes "autonomous

[13] W. Leontief, A. Carter, and P. Petri, *The Future of the World Economy: A United Nations Study* (New York: Oxford, 1977), p. 11; emphasis added.

[14] Ibid., pp. 5, 45.

Figure C-10.– Long-Term Consequences of U.S. Energy Self-Sufficiency Under World integrated Model "Fast-Nuclear"s Scenario



SOURCE: Systems Research Center, Case Western Reserve University.

substitution" between energy sources, but it does not rely on cross-price elasticities nor does it compute prices endogenously. For example, it assumes that shale oil and gasified coal will replace petroleum and natural gas in North America before 2000, but it also assumes that the price of coal will decline despite a sevenfold increase in the price of natural gas.[15] In addition, UNIOWM assumes a growing substitution of nuclear for conventional fuels in the utility sector, although this assumption is not reported in the documentation.[16]

In all of its many scenarios, UNIOWM projects a tremendous increase in world consumption of minerals and energy between 1970 and 2000. The global demand for petroleum is projected to increase 5.2 times, natural gas 4.5 times, and coal 5.0 times 1970 levels. Rapid industrialization in the developing regions causes them to more than double their share of world energy consumption. The Middle East remains the major net exporter of petroleum, with output projected to rise almost eightfold—a projection that now appears unrealistic in view of subsequent OPEC production decisions, Non-OPEC developing regions, along with Western Europe and Japan, become increasingly dependent on imported petroleum; but the U.S. oil deficit disappears after 1990, apparently due to the development of shale oil and a sudden doubling of domestic coal consumption in the 1990's. Despite anticipated advances in mining technology and industrial efficiency, the percentage of capital stock used in resource extraction increases steadily in all regions, just as it did in World 3.

In the standard scenario, based on the U.N.'S International Development Strategy, the real price of natural gas increases by 656 percent and that of petroleum by 225 percent over the 1970-2000 period; but the price of coal—the most plentiful energy resource—actually declines by 14 percent in constant dollars.[17] In a second scenario based on "more generous" resource endowments, production and consumption levels change very little and extraction costs, although they rise later, are just as high by 2000. The most significant impact of higher reserve estimates is on trade deficits: this scenario reduces the balance-of-payments deficit of the developed regions by 50 percent, but the non-OPEC developing regions, after being better off in 1990, have accumulated greater debts by 2000 than they do in the standard, "conservative" scenario.

In a later policy test conducted for the U.S. Department of Commerce, UNIOWM indicates that aggressive fossil-fuel conservation in developing regions could reduce LDC trade deficits and thereby remove the main economic constraint to Third World development .18 Such a course would also increase LDC capital requirements and (implicitly) would require an even greater nuclear share to provide adequate energy for continued industrial expansion. In general, the authors find energy to be an economic rather than a physical problem, at least until 2000: internal reform in the LDCS and the creation of a "new international economic order" are the necessary conditions for accelerated development in this century, although the model's restricted time horizon prevents it from examining the sustainability of such growth in the next century.

Global 2000

The energy projections in the Global 2000 Report include a variety of short-term and midterm forecasts, based on different methodologies and assumptions, whose purpose is "to define a range of credible futures against which alternative policy options can be tested. "19 The report's estimates of total world reserves

[15]Ibid., p. 65.
[16]A. Carter, private communication, April 1981.

[17]Leontief, Carter, and Petri, op. cit., p. 65, table 61; these projections, like those for production, appear unrealistic in view of subsequent events.
[18]A. P. Carter and A. K. Sire, "An Energy Conservation Scenario for the World Model," prepared for the Bureau of International and Economic Policy, U.S. Department of Commerce, November 1977, p. 2.
[19]J. Pearson, et al., "Energy Projections," in *The Global 2000 Report to the President* (Washington, D. C.: U.S. Council on Environmental Quality and Department of State, 1980), vol. 2, p. 173.

of fuel minerals come from figures prepared by the World Energy Conference, the Congressional Research Service, and the U.S. Geological Survey; but these reserve estimates are not used as inputs to the production or consumption forecasts, The short-term projections (1975-90) were prepared by the Department of Energy's Energy Information Administration (EIA) soon after its creation in late 1977, using two similar computer models: the Project Independence Evaluation System (PIES) for U.S. figures, and the International Energy Evaluation System (IEES) for global figures. The forecasts made for the Global 2000 study use the study's low, medium, and high growth-rate assumptions for population and GNP, but the energy projections were not used as inputs for other sectors; in essence, "GNP is implicitly treated as independent of the energy market."[20]

Both PIES and IEES are equilibrium market simulations, in which producers compete to satisfy short-term world demand and the entire global energy system is assumed to act in such a way as to minimize total costs without regard for the future value of the resources. As a result, both models assume that unlimited world oil supplies will be available at prices (determined outside the models) that rise from $13/barrel in 1978 to $23/barrel in 1990. The models contain detailed representations of the OECD countries and the major fuels, but they contain no representation of resource depletion or political factors and only simplified demand equations for the growing LDC market. The models assume that coal and nuclear will substitute for oil in response to price elasticity, but they impose no limit on the creation of new generating capacity in the utility sector. (The number of new generating plants is determined by expert judgment rather than price, a procedure that may be reasonable for forecasts through 1990: the lead time for developing new productive capacity is so long that current investment plans are a good guide to what will happen in the next 10 years.)

EIA was unwilling to extend its IEES forecasts beyond 1990, and Global 2000's midrange energy projections (1985-2000) are based instead on four different studies representing diverse philosophical and methodological approaches, as well as different assumptions about future demand growth and fuel substitution (see fig. C-11):

- the Workshop on Alternative Energy Strategies study, based on estimates from independent national experts, predicts global supply-demand "gaps" of 15 million to 20 million barrels of oil per day by 2000 and examines the consequences of choosing either nuclear or coal as the major replacement;
- the World Energy Conference study, after examining different assumptions about world oil reserves and recovery rates, predicts that global production will peak at a ceiling of 82 million to 104 million barrels per day around 1990, and emphasizes coal and hydropower as replacements when oil supply falls short of demand;
- the Stanford Research Institute (SRI) model of the U.S. energy market through 2020 (see below), which foresees a relatively plentiful energy supply based on coal but assumes perfect consumer foresight about future shortages and prices; and
- a Brookhaven National Laboratory/Dale Jorgenson Associates study of the U.S. energy market, which emphasizes conservation and coal as well as the development of nuclear and renewable sources.

In general, to the degree that these diverse projections can be compared, Global 2000 suggests that a rapid increase in the supply of energy will be needed through the end of the century, even with a declining rate of economic growth. Demand growth will be moderated only by price increases, and significantly higher oil prices will be needed to encourage substitution. Because petroleum production capacity is increasing more slowly than demand, a supply-constrained market is likely before 1990. Furthermore, because the rate of petroleum reserve additions is falling, world production is likely to peak between 1990 and 2010 and gradually decline thereafter. As a result, "a world transition away from petroleum dependence must take place, but there is still much uncertainty as to how this transition will occur."[21]

The findings suggest a considerable potential for coal and natural gas beyond 2000, but the short-term projections indicate that nuclear power will expand far faster than any other source, particularly if oil prices continue to increase. The potential contribution of solar and other renewable sources is rather limited at best. However, there does appear to be a substantial long-term potential for "aggressive, conservation-induced reductions in energy consumption."[22] The alternative energy systems examined in the different studies indicate that options do exist, however limited, and that current decisions about the future fuel mix will have increasingly significant impacts after 2000.

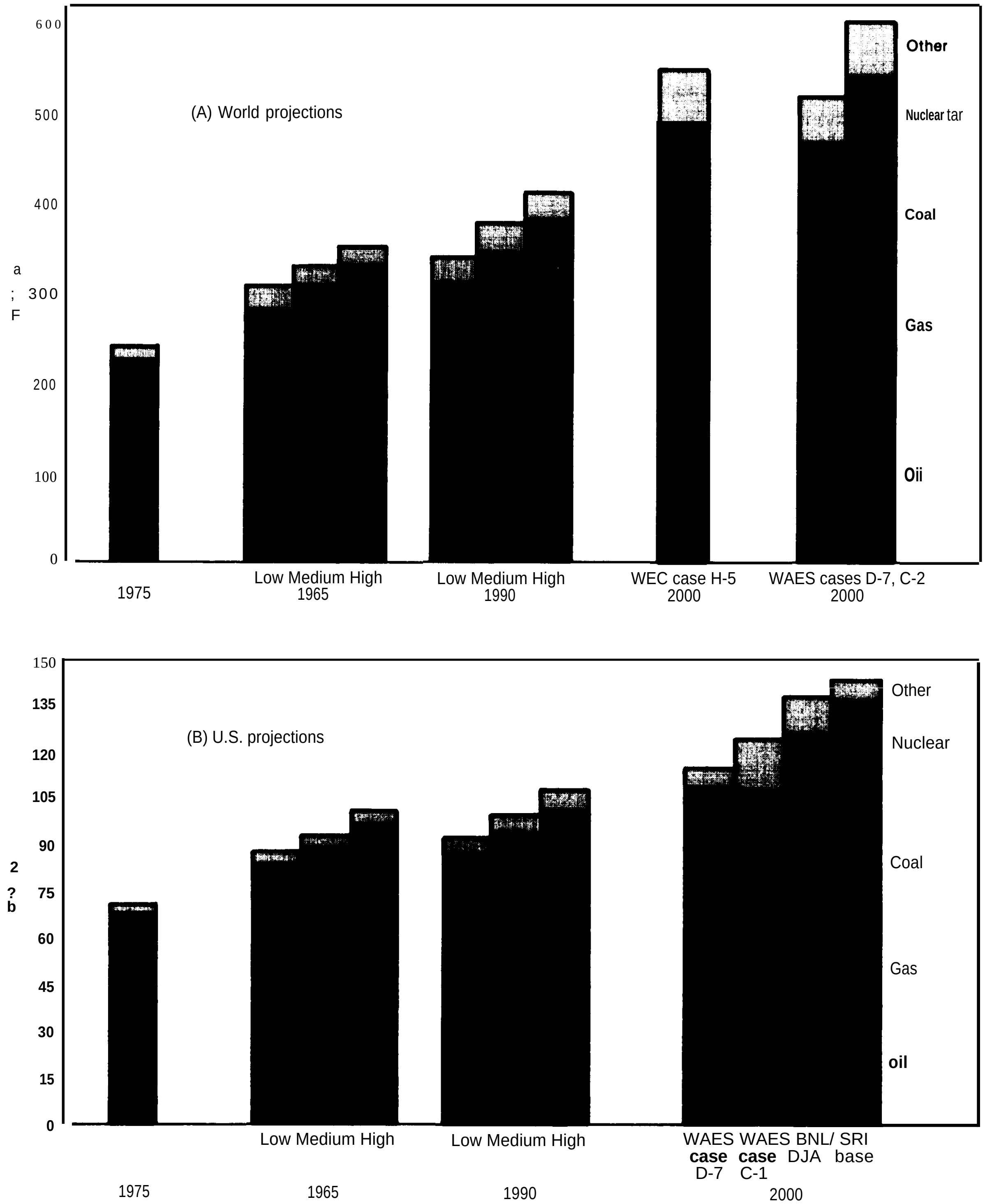
Other Energy Projections

Concurrently with its PIES/IEES short-term global projections, EIA also produced a set of long-term (1978-2020) energy projections for the United States using the Long-term Energy Analysis Program (LEAP), an up-

[20] VanderWerf, op. cit., vol. 2, p. 571.

[21] *The Global 2000 Report to the President*, vol. 1, p. 27.
[22] Pearson, et al., op. cit., p. 161.

Figure C-II.–Comparisons of Global 2000 Projections of World and U.S. Energy Consumption and Supply Mix, 1975-2000



SOURCE: *The Global 2000* ***Report*** *to the President.*

dated version of the SRI -energy model (see above).[23] This forecast, which was not reported in the Global 2000 Report, describes the energy requirements for continued economic growth in the United States during a transition from oil to coal and nuclear power. It assumes the rapid development of shale oil and synfuels to replace oil imports, as well as an ambitious level of energy conservation: a 48-percent reduction in the energy-consumption-to-GNP ratio, based on improvements considered possible on the basis of known technologies, with almost no increase in residential consumption and most of the demand growth coming in the industrial sector. It also assumes that the rate of real GNP growth will decline to 2.4 percent by 1995. Despite these assumptions, the SRI model's projections would require U.S. coal production to triple by 2000 and reach 5 times present levels by 2020; nuclear power would increase eightfold by 2000 and reach 16 times present levels by 2020. This vast expansion is required partly to satisfy growing industrial demand, but primarily because coal and nuclear must grow from 23 percent of primary energy to 72 percent in order to replace depleted U.S. oil and gas. (This energy supply mix corresponds roughly to the "fast-nuclear scenario" that was tested with WIM; see figs. C-9 and C-10, above).

EIA's Office of Energy Information Validation has conducted an evaluation of this 1978 forecast, and their report cites a number of factors that might modify these projections:[24]

- statistical studies of U.S. oil reserves suggest that there may be only half as much domestic oil available as previously estimated by the U.S. Geological Survey and assumed in the forecast;
- recent studies show that the actual costs for shale oil and synfuels may be two to four times greater than earlier engineering estimates, and that there are severe physical constraints on the development of a massive synfuels industry;
- the forecast assumes that extraction costs for coal and uranium will not increase significantly over time due to depletion or scale, and that environmental consideration will not impede the development of these industries;
- the forecast does not address the capabilities of the relevant industries and therefore fails to consider potential bottlenecks and constraints, including the need to build up the U.S. railroad system, a potential shortage of engineers and deep-seam miners, the risk aversion and capital constraints of potential consumers, and the potential efforts of State governments to prevent rapid expansion in the West; and
- more recent data, and more realistic technical assumptions, suggest that electric cars can capture 50 percent of the U.S. personal-transportation market by 2000—despite optimistic oil prices and moderate consumer prejudice—if automobile companies can acquire enough capital to keep up with the potential market.

These and other problems are discussed in more recent forecasts by EIA, which continues to refine, validate, and expand its energy modeling capability; but despite a number of structural changes in the models, the 1980 forecasts are based on many of the same assumptions as the Global 2000 projections.[25] Midterm global energy projections (1975-95) now come from an improved version of the IEES model that incorporates the annual oil production capacity forecasts provided by DOE's Office of International Affairs and the oil price forecasts generated by the Oil Market Simulation (OMS) Model. OMS assumes that OPEC will raise oil prices only when world demand requires them to use almost all of their annual production capacity, and it also reflects lower rates of economic growth. Oil prices are projected to reach $50/barrel in constant mid-1979 dollars by 1995, with almost no increase in oil consumption between now and then. This projection assumes, however, that all OECD nations will reach their official conservation targets and that higher prices will lead to further substitution away from oil. Coal is projected to provide a slightly larger share of total energy demand; nuclear projections are lower due to lower estimates of the speed with which new reactors will be built.

Long-term U.S. energy projections (1975-2030) now come from LEAP, a descendent of the SRI model that EIA used in 1978. LEAP still assumes an unlimited supply of oil imports, at the OMS/IEES world price, but it predicts that the United States will require far fewer imports over the next 40 years. This is due in part to conservation and in part to massive deployment of shale oil and synfuels: U.S. oil consumption is cut in half between 1978 and 2020; and of the remaining demand for liquid fuels, coal-based synthetics provide 50 percent, shale oil 27 percent, and conventional oil only 23 percent. This assumes that the goals of the Synthetic Fuels Corp. (1.5 million barrels per day by 1990 and 3.0 million by 1995) will be met or exceeded, and that, there will be virtually no constraints on the expansion of the synfuels industry after 1995. This projection also accepts with little modification the current engineering estimates of synfuel costs; sensitivity tests, using capital costs twice as high as these estimates, lead to an in-

[23] Energy Information Administration, *Annual Report to Congress 1978* (Washington, D. C.: Department of Energy, 1979), vol. 3.

[24] Office of Energy Information Validation, *Analysis Quality Report: 1978 Long-Term Forecasts and Methodology* (Washington, D. C.: Energy Information Administration, 1981).

[25] Energy Information Administration, *1980 Annual Report to Congress* (Washington, D, C.: Department of Energy, 1981), 1,01, 3.

crease in U.S. oil imports through 2020. LEAP also assumes an upper limit to the net contribution of renewable energy sources (hydro, wind, biomass, small-scale solar, etc.) of about 6 percent of U.S. demand in 2020.[26]

Strengths and Weakness of Energy Projection Techniques

All of these models are generalized analytic tools that can accommodate a variety of assumptions and serve a variety of applications. Some of them have features that limit their usefulness in examining the future of the global energy system, but these features were usually appropriate to the models' original purposes. World 3, for instance, was intended to give a generalized description of the long-term behavior of the entire global system except agricultural land; as a result, it treats energy only as part of a highly aggregated "nonrenewable resources" sector and makes no specific projections of energy supplies or prices. LAWM explicitly excludes all resource constraints except agricultural land; it assumes that energy and other resources will be available and concentrates instead on how they should be allocated in order to satisfy basic human needs. UNIOWM and Global 2000, because of their shorter time horizons and the absence of resource depletion in their structures, are ill-suited for examining the long-term effects of resource depletion. In addition, UNIOWM concerns itself primarily with development targets and trade balances—although it treats the energy sector in detail, it does little more than tabulate resources as they are consumed in meeting those goals. Global 2000's IEES projections represents major producers and consumers of oil in detail, but they contain considerably less detail for other fuels or for the rapidly growing Third World market. Furthermore, Global 2000's energy projections do not interact with other sectors and therefore do not reflect competing demands for energy resources. WIM strikes a balance between detail and generality, and its policy levers provide more flexibility than the other models for testing alternative energy futures and different producer and consumer behavior. Because of its complexity and lack of documentation, however, the value of WIM's conclusions may not have been fully tested or understood.

Factors Affecting the Accuracy and Reliability of Energy Projections

These differences in purpose and technique have an influence on the projections generated by the different models, but the accuracy and reliability of these projections are also affected by a number of factors and uncertainties on which there is presently little general agreement or understanding. Among these factors are the following:

- total resource reserves and future prices;
- population and GNP growth rates;
- conservation;
- Third World energy choices;
- development bottlenecks; and
- future energy breakthroughs.

Total Resource Reserves and Future Prices

Table C-1 shows the estimates of total world reserves of conventional energy resources on which the different models are based. There is little agreement among the models on the size of these reserves or, how they should be measured, and even less agreement on the costs of extracting them. In general, however, those models that consider prices show that lower grades and unconventional sources will become available as prices rise. Extraction cost will be higher for these low-grade deposits, however, and recovery rates will be significantly lower. Consequently, a steadily larger percentage of capital will have to be allocated to obtaining resources, leaving less capital for investment in other sectors. Improvements in extraction and processing technologies might modify this trend, but recent studies have shown that capital costs for shale oil and coal synfuels are likely to be higher rather than lower than previously estimated.

Several of the models predict an energy future based on abundant reserves of coal, but estimated total reserves of coal have increased little since 1913, when they were estimated at 8,000 billion metric tons.[27] Of the 9,000 billion metric tons now generally agreed upon, 50 percent or less is recoverable with current techniques, and two-thirds are reserves claimed by the U.S.S.R. that some experts treat with skepticism. Until recently, however, there has been little incentive for further exploration; new deposits may soon be discovered due to renewed interest in coal.

[26]For further assessment of the technologies and assumptions involved in these projections, see the following OTA reports and technical memoranda: *Nuclear Proliferation and Safeguards*, OTA-E-48 (June 1977); *Gas Potential From Devonian Shales of the Appalachian Basin*, OTA-E-57 (November 1977); *Enhanced Oil Recovery Potential in the United States*, OTA-E-59 (January 1978); *A Technology Assessment of Coal Slurry Pipelines*, OTA-E-60 (March 1978); *Application of Solar Technology to Today's Energy Requirements*, OTA-E-66 (June 1978); *The Direct Use of Coal: Prospects and Problems of Production and Combu.men*, OTA-E-86 (April 1979); *Gasahol: A Technical Memorandum*, OTA-TM-E-1 (September 1979); *The Future of Liquefied Natural Gas Imports*, OTA-E-110 (July 1980); *Energy From Biological Processes*, OTA-E-124 (July 1980); *Wodd Petroleum Availability 1984) -2(3(XI: A Technical Memorandum*, OTA-TM-E-5 (October 1980); *Nuclear Powerplant Standardization: Light Water Reactors*, OTA-E-1 34 (April 1981).

[27]H. S. D. Cole (ed.), *Models of Doom: A Critique of the Limits to Growth* (New York: Universe Books, 1973), p. 98; on the other hand, these reserves have seemed so large relative to expected demand that there has been little incentive for increased exploration.

Table C-l.—Energy Resource Reserves as Described by Five GLobaL Modeling Studies

Global model	Year	Petroleum (billions of barrels)	Natural gas (trillions of ft)	Coal (billions of metric tons)	Uranium oxide (millions of metric tons)
World 3	1972	630 ident[a] 1,200 hyp/spec[b]	1,000 ident 10,000 hyp/spec	8,600 ident 6,600 hyp/spec	N/A
WIM	1974	667 proven	285 proven 2,300 ultimate[c]	4,200 recoverable 8,400 total[d]	Implicitly unlimited
LAWM	1976	1,800 total	103 total	9,640 total	0.76 @ $10/lb; practically unlimited @ $20/lb
UNIOWM	1977	1,555 total	N/A	9,080 total	NIA
Global 2000	1978	646 proven 2,100 total	2,520 proven 5,984 hyp/spec	786 proven 12,682 total	1.661 @ $10-$35/lb 2.794 additional at higher prices

N/A = not available.
[a]Identified reserves include both proven and inferred reserves, including deposits that are currently subeconomic.
[b]Hypothetical resources include undiscovered deposits in known districts; speculative resources include undiscovered deposits in districts not presently known to contain deposits.
[c]Ultimately recoverable reserves; total reserves greater.
[d]Assuming that 50 percent of total is recoverable.

SOURCE: Office of Technology Assessment.

The rate at which new petroleum reserves are being discovered, on the other hand, appears to be falling. In addition, many geologists are pessimistic about the prospects for discovering vast new reserves of natural gas at greater depths than have been explored thus far.

There is as yet no indication of diminishing returns in uranium exploration. Current reserves (including speculative reserves at much higher prices) represent less than 50 years of total world energy supplies at current consumption levels (assuming the use of conventional nuclear reactors), although with breeder reactors these reserves would last far longer. Technologies for extracting huge amounts of uranium from granite or seawater remain speculative, and DOE has at times taken the position that uranium is scarce enough to justify the deployment of the breeder reactor.[28]

Finally, none of the models deals with potential reserves of lithium. Despite the LAWM team's confidence that fusion power will solve the world's long-term energy problems, successful development and widespread deployment of this technology remains speculative (see below).

Population and GNP Growth Rates

Appendix A shows that there is general agreement among the projections of world population in 2000, however much the projections differ in the longer term. There is far less agreement among the models on future rates of economic growth. Both factors influence the energy projections, although the effect of GNP projections is somewhat greater.

The standard run of World 3 assumes that population will continue to grow exponentially. It also assumes that the recent rate of world economic growth, 1.7 percent per year measured in real GNP per capita, will also continue through 2000. These two factors quickly force the model against its resource limits, and the global economic system collapses sometime after 2010 due to rising extraction costs. Sensitivity tests indicate that policies designed to slow population growth or limit industrial expansion could delay (but not prevent) this collapse. Critics have claimed, however, that World 3 underestimates the ability of the free-market system to anticipate and thereby prevent a possible catastrophe, although they have not explained how it would be possible to prevent such a catastrophe in the absence of specific new energy sources.[29]

UNIOWM assumes a slightly faster population growth and a much higher growth rate for gross product per capita—3.0 percent per year even in its most pessimistic "business as usual" scenario, and as high as 6.0 percent per year for the LDCs in other scenarios. The model does not examine the long-term sustainability of these growth rates, however, and the principal reason why UNIOWM does not predict a catastrophe is that it stops at 2000.

LAWM's population projections are higher still, particularly in the longer term, and its optimization procedures impose high investment rates that lead to economic growth rates of 4.0 percent per year for the devel-

[28]U.S. Atomic Energy Commission (USAEC), Proposed Final Environmental Statement Liquid Metal Fast Breeder Program (Washington, D.C.: National Technical Information Service, 1974).

[29]Cole, op. cit., p. 66

oped regions and up to 6.0 percent for the LDCs through 2000, gradually declining thereafter to 2.0 and 3.0 percent, respectively. These growth rates do not lead to an energy-related catastrophe because LAWM contains no representation of resource availability.

WIM assumes relatively ambitious population control in many of its scenarios. Even so, it shows that population will not stabilize before 2050 under the best of conditions. Economic growth varies considerably among scenarios, but in at least one policy test the economic growth rate (supported by investment aid from developed nations) remains at 7.0 percent in Latin America and 8.2 percent in South Asia through 2025.

Global 2000's short-term projections test three different sets of population and GNP growth assumptions, in order to illustrate a range of possible futures. Economic growth rates are highest for OPEC and medium-income LDCs, somewhat lower for the developed nations, and lowest for the low-income LDCs and Communist bloc. In all cases, economic growth slows significantly after 1985.

Conservation

Total demand for energy can be represented as the product of three variables: population and GNP per capita (see above), and the ratio of energy consumption to GNP. Conservation can reduce this latter ratio (and thus the total demand for oil and energy at any given level of population and GNP per capita) in either of two ways: 1) by improving the efficiency with which energy is used (e.g., through residential insulation or improved industrial machinery); or 2) by improving the way in which the overall energy system matches energy sources with particular end uses (e.g., a large-scale coal or nuclear generator is more appropriate to the energy needs of a major industrial city than to those of a rural village, which might well be better served by a small-scale wind, hydro, or solar source). Biomass, dispersed solar, and other small-scale alternatives can contribute to the second form of conservation, but conservation of conventional fuels will depend primarily on the response of large-scale industrial and utility consumers.

Many economists believe that higher prices are an efficient mechanism for inducing this kind of conservation, and economic models generally assume that demand will fall in response to future price increases to the same degree that it has in the past. For example, pre-embargo studies of energy demand in the United States generally showed little responsiveness to price: when prices were low, other variables (such as the price of automobiles or new capital equipment) are more important to consumers than energy costs. As prices first began to rise rapidly, there was a large initial demand response due to "housekeeping" conservation and other simple measures, but the long-term response was expected to be slower due to the slower conversion to more efficient automobiles and capital equipment.

However, the response to the 1979 oil price hike suggests that long-term elasticity will be greater than many people had expected. Conservation has been greater—and demand growth slower—than was previously foreseen, even when the effects of economic slowdown are eliminated. In addition, some economists claim that economic models based on the United States do not reflect the full global potential for long-term conservation through more efficient capital equipment. JO Other studies, however, have shown that technological progress in some critical industrial sectors requires an increasing use of energy per unit of output .31

The World 3 standard run assumes that resource consumption per capita will continue to be a fixed function of GNP per capita. This assumption implicitly rejects any significant potential for conservation and—although reasonable when the results were published in 1972–it gives the standard run a pessimistic bias that has been contradicted by subsequent events. However, World 3's "recycling" run (fig. C-5) does show that conservation, in combination with improved exploration and extraction technologies, can have a significant impact on resource depletion.

WIM, published after the 1973 embargo and price hikes, does assume some conservation in response to higher prices. In the case of oil, a l. O-percent increase in price is converted into a direct decrease of 0.225 percent in consumption, plus additional decreases due to substitution. The authors conclude, however, that even optimistic assumptions about conservation will not prevent a substantial increase in total energy demand—the world will need to develop alternative sources, either nuclear or solar.[32]

LAWM assumes that the global energy system will make more efficient use of different energy sources in the future, and that technological progress will increase the productivity of the capital goods sector by 1.5 percent per year (a rate that would double the output-to-input ratio in 47 years). For the most part, LAWM's optimism about the availability of energy is based not on conservation but rather on unlimited supplies of nuclear power, including the deployment of fusion technology within 50 years.

UNIOWM also assumes that technological progress will change the energy requirements of every sector. The documentation does not reveal, however, the pre-

[30] R. S. Pindyck, "The Characteristics of Demand for Energy," in J. C. Sawhill (cd.), *Energy Conservation and Public Policy* (Englewood Cliffs, N.J.: Prentice-Hall, 1979), pp. 38, 39.

[31] D.W. Jorgenson and B.M. Fraumeni, "Relative Prices and Technical Change," prepared for AEA Annual Meeting in Denver, Colo., Sept. 5, 1980.

[32] Mesarovic and Pestel, op. *Cit.*, p. 136.

cise value of these assumptions or how sensitive the results are to them.

Global 2000's short-term projections assume energy conservation in response to price ($23/barrel in 1978 dollars by 1990), above and beyond the official conservation targets of various national governments. The midterm projections extrapolate from engineering and economic forecasts for 1995 and result in a final level of conservation—48 percent reduction in the energy-to-GNP ratio by 2020–that indicates the technological limits of what can be achieved. More recent DOE forecasts of conservation are based on higher prices ($50/barrel in 1979 dollars by 1995) and on detailed analyses of specific technological possibilities in every end-use sector, many of them derived from engineering studies conducted by the Oak Ridge National Laboratory. These and other studies, combined with the demand response to the 1979 oil price hikes, suggest that long-term conservation in the 50-percent range is in fact a reasonable expectation.

Third World Energy Choices

None of the models except Global 2000 deal with the firewood crisis, which may have severe social and environmental repercussions in many Third World countries. Industrialization and economic development in these countries will also require electricity, however, and all of the models assume, at least implicitly, that nuclear power will be widely deployed in the future. This common assumption is of political as well as economic interest, particularly in the case of LAWM and UNIOWM. Both of these models represent Third World attempts to chart a future in which the gap between the rich and poor nations is narrowed through local and international efforts to accelerate development and increase industrial output. Nuclear power offers developing nations an alternative to their current dependence on fossil fuels, whether to preserve their domestic resources or to reduce their energy-related trade deficits. There is evidence that, whether or not the United States and other OECD nations finally accept the hazards of nuclear power, many Third World nations are likely to accept them on a very large scale, and very soon, for lack of a credible large-scale alternative.

Business commentators already speak of "the nuclear power boom getting under way in the Third World," including such nations as Mexico, Egypt, Korea, Taiwan, and the People's Republic of China.[33] Conventional enriched-uranium reactors in such countries represent a potentially lucrative market for the U.S. and European nuclear industries. Many Third World governments are also investigating natural-uranium technologies that would allow them to exploit domestic uranium rather than depending on Europe or the United States for expensive enriched fuel. Argentina, Pakistan, India, and South Korea already have operational reactors based on a Canadian natural-uranium, heavy-water system. Mexico's recently published National Energy Program calls for the construction of as many as 16 such reactors to meet a tripling of demand for electricity by 2000, despite that nation's abundant oil and gas reserves .34

The WIM "fast-nuclear" scenario, however, foresees an energy future based not on conventional fission but rather on the more efficient "breeder" reactor, which effectively produces more nuclear fuel than it consumes. As a result, breeder reactors might produce 60 to 100 times as much energy from a pound of uranium as do conventional reactors. Both past U.S. Government studies and current expert opinion suggest that, given the limited size of world uranium reserves (even including speculative reserves), nuclear fission may not be able to provide a large-scale, long-term contribution to the world's energy supply without the widespread use of breeder reactors.[35] Because breeders would also produce large quantities of weapons-grade plutonium, however, their deployment throughout the Third World could also pose a serious threat to domestic and international security.

Development Bottlenecks

Some economists would argue that the world's major energy problem is not finding adequate resources, but rather overcoming the bottlenecks in getting those resources to market. Three of the models considered here —World 3, LAWM, and UNIOWM—implicitly assume that there will be no major bottlenecks in the exploitation of energy resources. Although WIM's authors point out the numbers and speed with which reactors would have to be built for the "fast-nuclear" scenario, they do not report any further analysis of development bottlenecks. DOE's models for Global 2000 involve a serious attempt to address problems of timing where they involve liquid fuels and the transition from oil to coal and nuclear power. However, DOE's own evaluation of the 1978 long-term forecasts points out that the models describe the requiremenrs for U.S. energy independence rather than the capabilities of the relevent industries, as well as making questionable assumptions about investor foresight, extraction costs, and environment constraints (see above). Further consideration of these and other factors suggest both that considerable cooperation between Government and industry may be needed to reduce the impact of these potential bot-

[33] H. Rowen, "Nuclear Reactors: Fear of Losing Export Race," *Washington Post*, May 17, 1981, p. K1.

[34] C. Dickey, "Scenic Mexican Reactor Site Entangles Indians, Unions, Nationalists," *Washington Post*, May 18, 1981, p. A12.

[35] See, for example, USAEC, op. cit.

tlenecks, and that other energy sources and mixes should be examined more carefully.

Future Energy Breakthroughs

Finally, the accuracy and reliability of energy projections will also be affected by the assumptions they make about the successful development and deployment of entirely new energy sources. Some such systems are implicitly assumed by one or more of the models, but others are not foreseen by any of them.

The widespread deployment of fusion technology, for instance, could possibly invalidate the pessimistic assumptions of Limits to Growth if the supply of lithium were large enough or if deuterium-deuterium fusion were developed. The LAWM study bases its exclusion of resource problems in part on the expectation that fusion power will in fact be deployed within 20 to 50 years. Commercial-scale fusion power remains purely speculative at present, however. Although fusion researchers hope that a commercial fusion reactor design might be possible by 1990, until then all claims about engineering problems, capital costs, and net energy production will also remain speculative. In addition, none of the models discusses the potential world reserves of lithium. Other sources, however, have estimated that minable U.S. lithium reserves alone are worth over 160,000 quadrillion Btu prior to conversion losses, or about 640 years total world energy supply at 1976 consumption levels.[36]

The WIM solar scenario envisions a long-term energy future based on centralized solar power in the form of huge "solar farms" in the deserts of the Middle East, to be financed by OPEC oil money.[37] With higher energy prices due to scarcity, the capital costs of such facilities—which the authors estimate at $20 trillion to $50 trillion in 1974 dollars—might become bearable; solar might even prove cheaper than nuclear. Theoretically it would be possible to supply all of the present U.S. demand for electricity from a "farm" of solar cells the size of Massachusetts, but DOE studies claim that there are not enough economically feasible sites in the United States for centralized solar to make more than a marginal contribution to U.S. energy supply in the foreseeable future.[38] On the vast scale foreseen by Mankind at the Turning Point—1 percent of the world's land surface–such facilities would involve scientific, engineering, and planning problems that are beyond the current state of the art. Furthermore, some critics question whether the energy produced by these solar farms would be greater than the total amount of energy involved in building them, maintaining them, and distributing the hydrogen and electricity they would produce, Since this scenario was not subjected to rigorous testing with the model, it remains speculative.

A number of other groups have suggested another alternative: solar-power satellites orbiting in space and beaming power down to earth in the form of microwaves or lasers, The National Aeronautics and Space Administration (NASA) has produced detailed designs for such a system, for which it envisions commercial operation by 2000, or about 20 years before fusion is predicted to become commercial. NASA studies have indicated that marginal costs and net energy production will be comparable to present energy sources, although these findings are highly controversial. DOE claims that potential receiving sites are probably more than adequate to supply several times the present level of U.S. electricity demand, since more energy can be received per acre than with central solar and without necessarily prohibiting agricultural uses of the sites, although the effects of low-level microwave radiation are problematic. Research and development costs for the NASA design, however, would be over $100 billion, and the cost per power station would be somewhat higher than that of conventional fission reactors regardless of the scale of production. An alternative design developed at Princeton University involves less R&D and employs small modular processing units whose cost and performance could be tested prior to any commitment to large-scale deployment. The Princeton design is somewhat riskier than NASA's, but it might be possible to deploy it sooner and to reduce energy costs substantially as the scale increases. This might in turn make it possible to sell energy to the LDCs at prices much lower than would be possible with breeder reactors.[39]

[36] S. S. Penner (e&), *Nuclear Energy* and *Energy* Politics (Reading, Mass.: Addison-Wesley, 1976), p. 562.

[37] Mesarovic and Pestel, op. cit., pp. 139-141.

[38] *Domestic Policy Review of Solar Energy* (Washington, D. C.: Department of Energy, February 1979), table 8; DOE's long-term forecasts therefore assume an a priori hmit of less than 1.0 Quad central solar by 2020.

[39] Further discussion and analysis of this technology can be found in the following sources: *Satellite Power* System *Concept Development* and *Evaluation Program* Reference *System* Report, DOE/ER-0023 (Washington, D. C.: U.S. Department of Energy and National Aeronautics and Space Administration, October 1978); The *Solar* Power *Satellite* Concept: The Past *Decade and the Next Decade*, NASA/JCS-14898 (Washington, D. C.: National Aeronautics and Space Administration, July 1979); R.A. Herendeen, T. Kary, and J. Rebitzer, "Energy Analysis of the Solar Power Satellite," *Science*, vol. 205 No. 4405, Aug. 3, 1979, pp. 451-454; Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, Space Systems Laboratory, *Extraterrestial* Processing *and Manufacturing of* Large *Space* Systems, NASA contract CR-161293 (Washington, D. C.: National Aeronautics and Space Administration, September 1979), vol. 3, pp. 47-49; Office of Energy Research, Solar Power Satellite Project Division, ***Program Assessment Report,*** DOE/ER-0085 (Washington, D. C.: U.S. Department of Energy, November 1980); and Office of Technology Assessment, U.S. Congress, *Solar Power* Satellites, OTA-E-144, (Washington, D. C.: U.S. Government Printing Office, August 1981).