CHAPTER 3

Findings of the Global Models

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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.

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.

[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.

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.

[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

[1]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 popu-

lation 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	Global 2000 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 f980-2000, 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.