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.

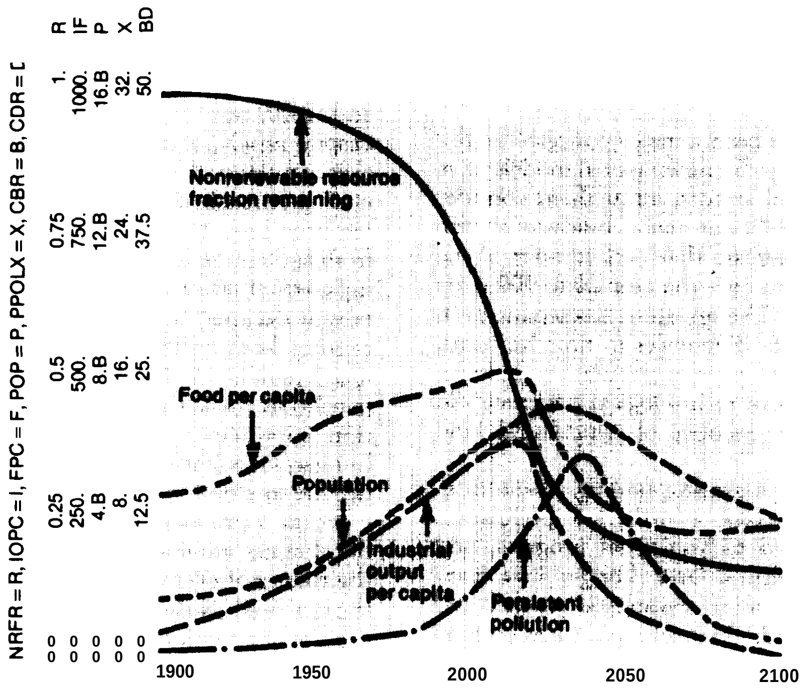
World Integrated Model (WIM)

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.

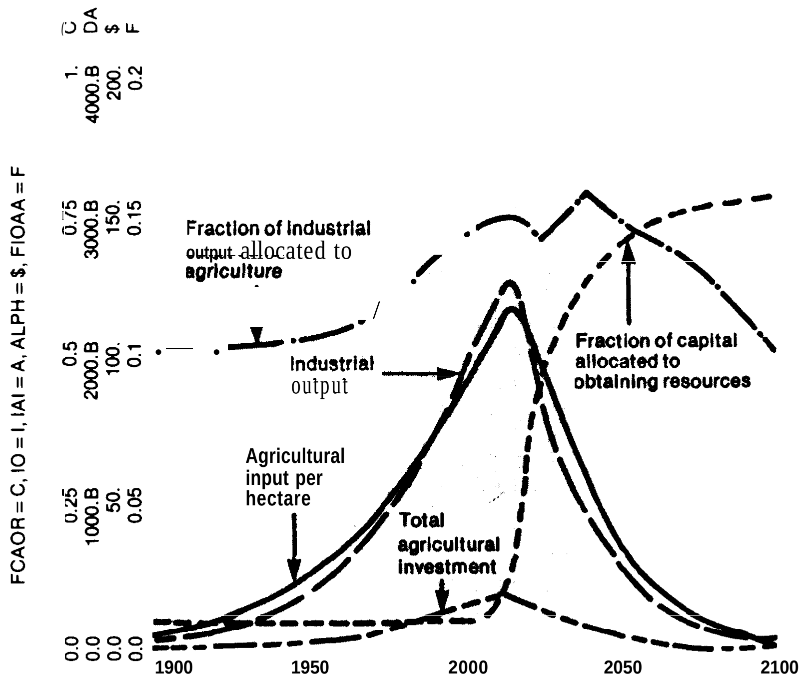
The WIM standard or "historical" scenario is based on a continuation of present trends, but it nevertheless makes some rather optimistic assumptions about agricultural progress in the developing regions. (The report focuses on South and Southeast Asia because of this region's existing food problems and 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.

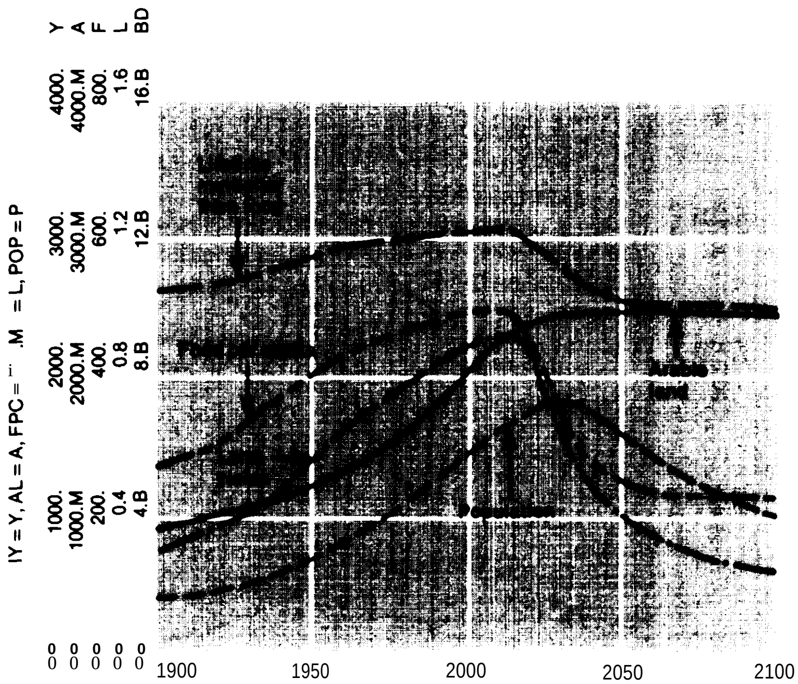
number of child deaths caused by malnutrition will double by 2005 (see fig. B-5).

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)

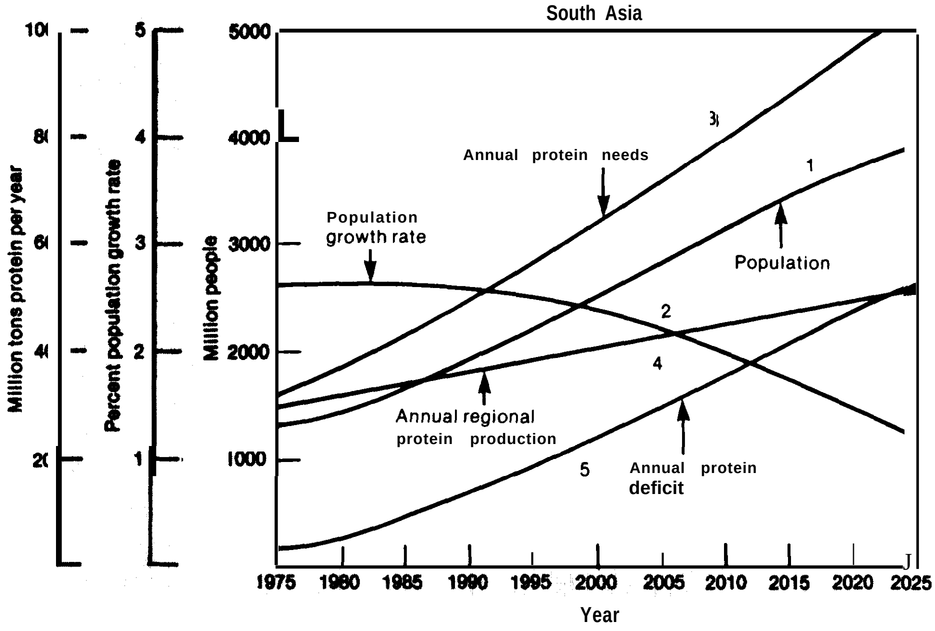
LAWM was developed to show that, given optimal resource allocation and the universal objective of satisfying basic human needs, the global system need not be troubled by physical limits. Because development proceeds "autarchically" in each of its four regions, international food trade is unimportant 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



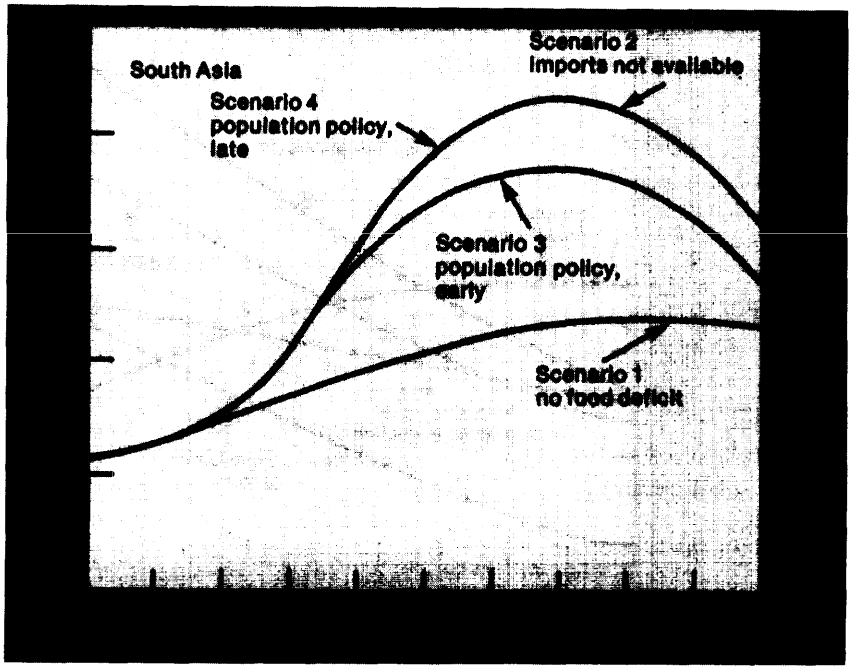
The "standard" scenario is based on the assumption that a population policy is initiated that leads in about 50 years to equilibrium fertility. Thereby, the population grows from 1.3 billion in 1975 to 3.8 billion in 2025 (curve 1) while the growth rate of this region declines from a little over 2.5 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.

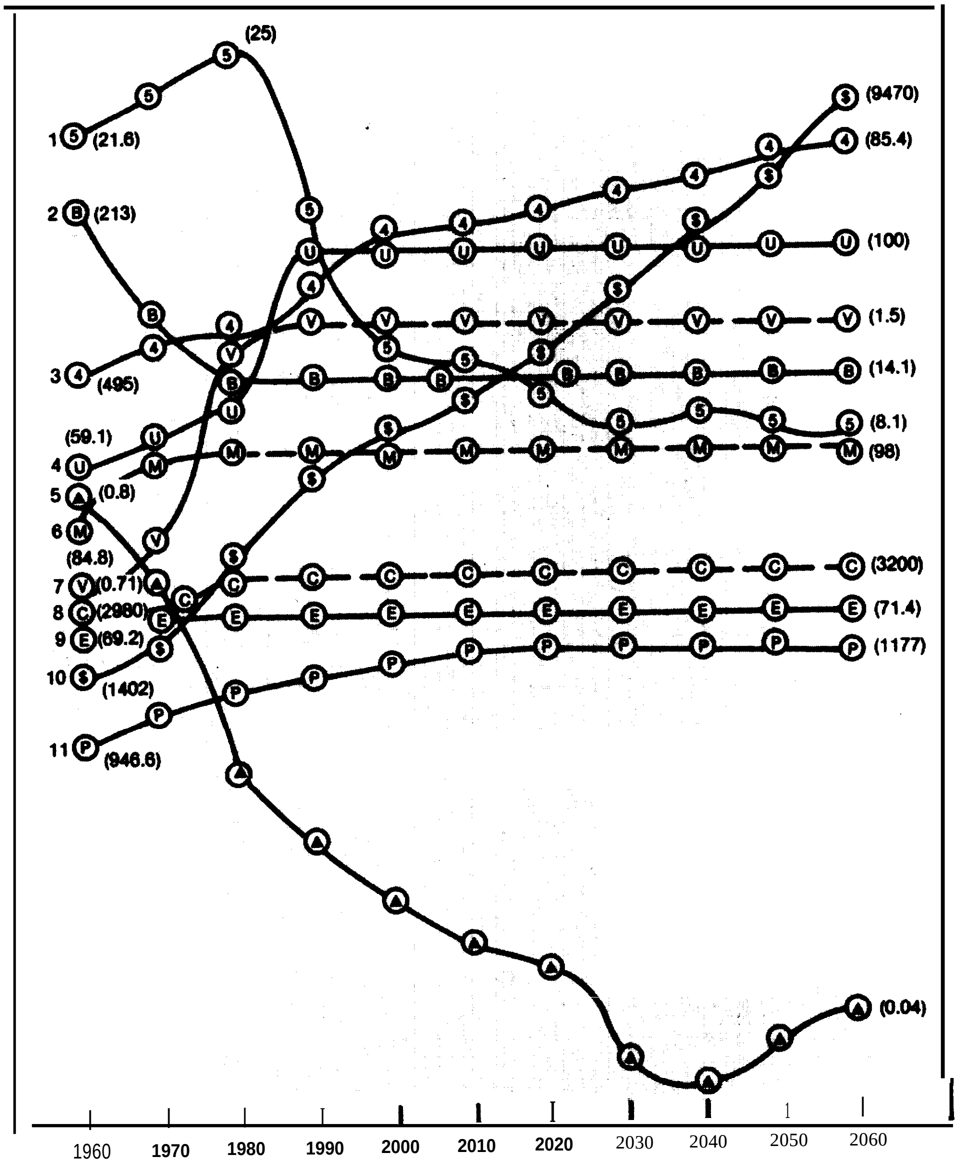
The policy tests that were conducted by the LAWM team indicate that capital transfers from the developed region would have a negligible impact on the food shortage in Asia. They also show that technological stagnation after 1980 would lead to a similar collapse in Africa as well as Asia and that, in 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

8 A. 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

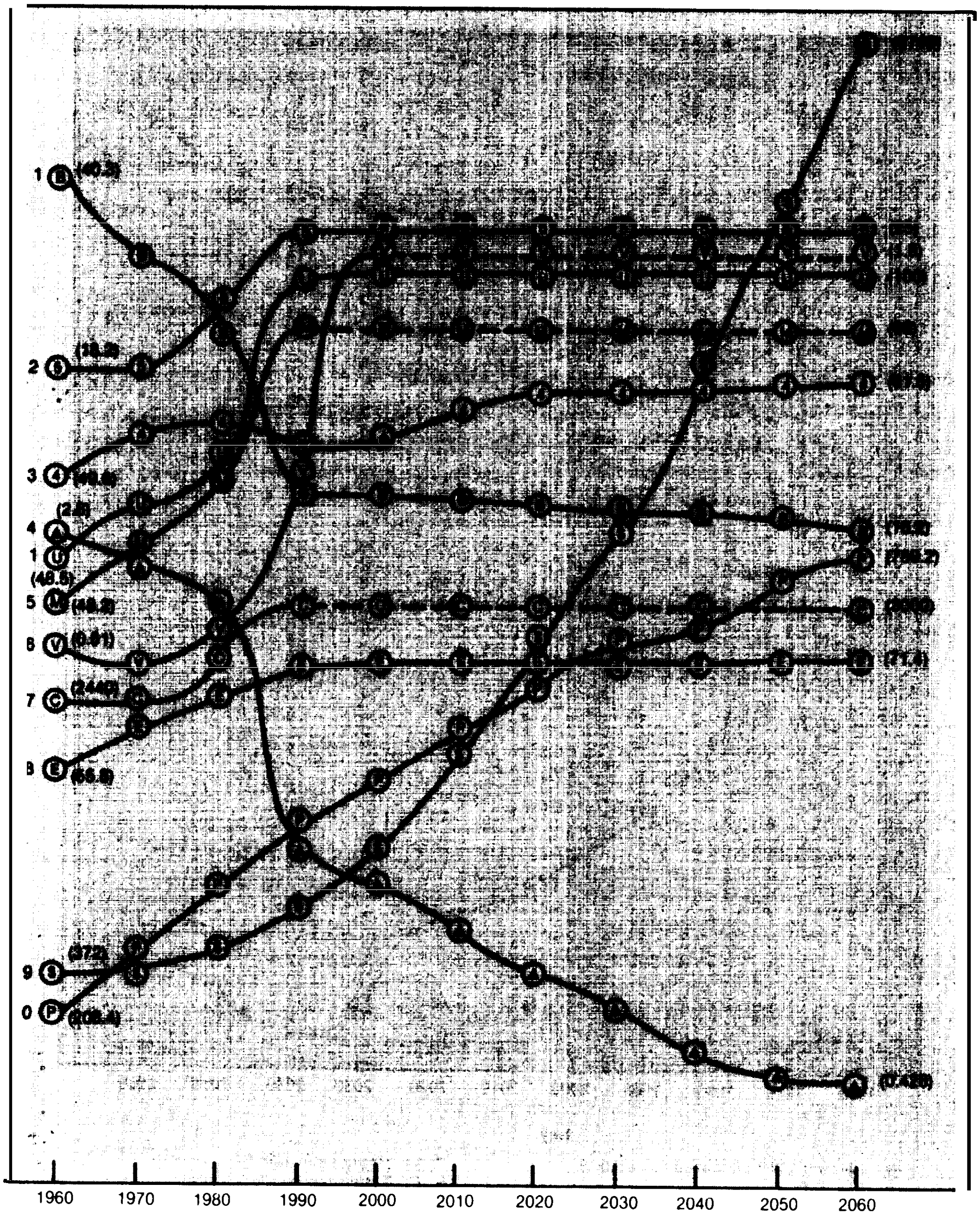


Key:

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

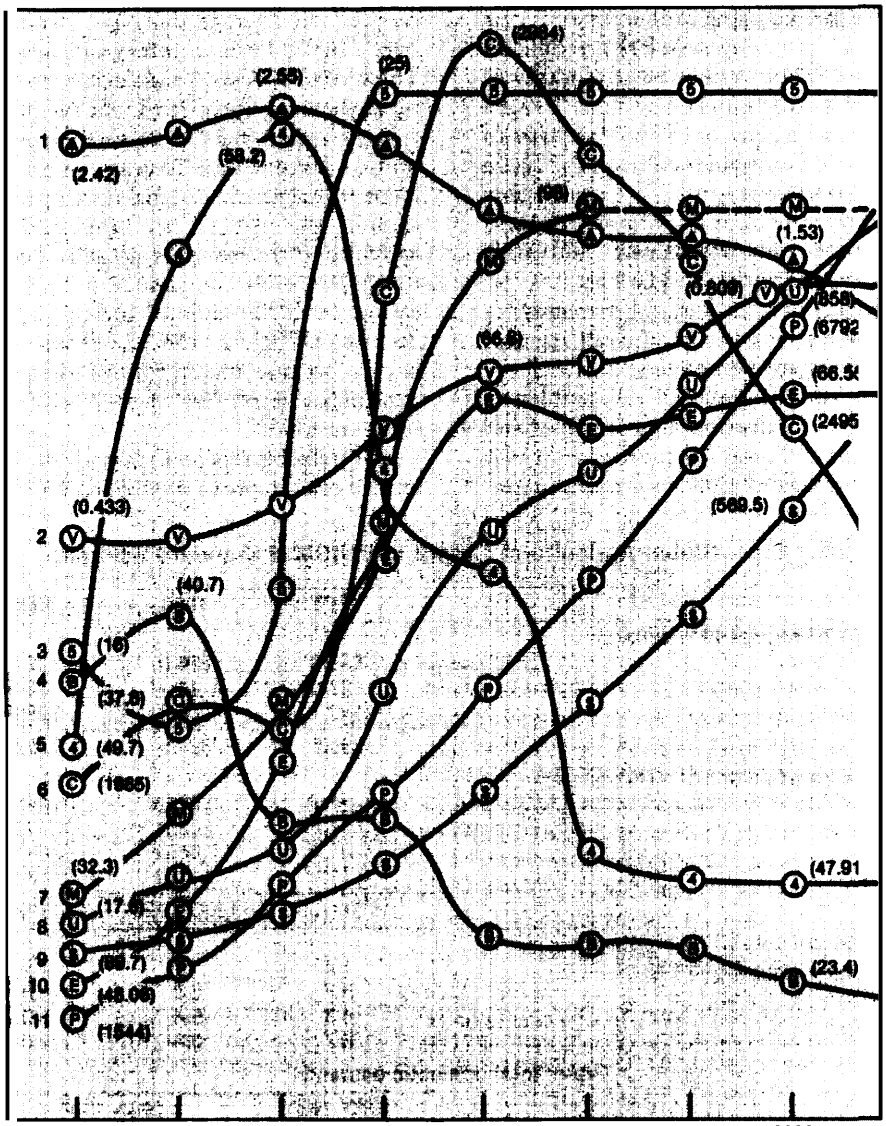


Key:

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- I.—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	Kilo-calories (thousands) 2000	Proteins (grams) 1970	Proteins (grams) 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.[14]

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]

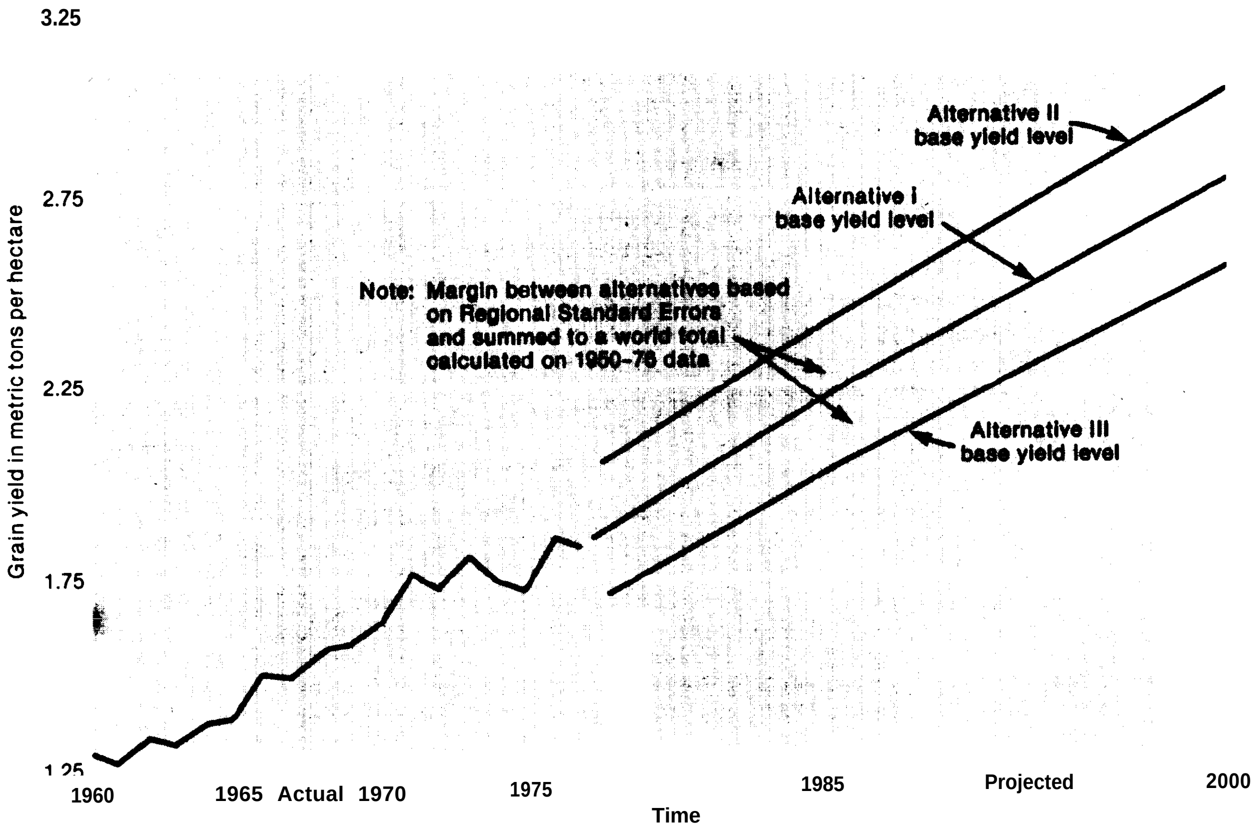
Other Agricultural Projections

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

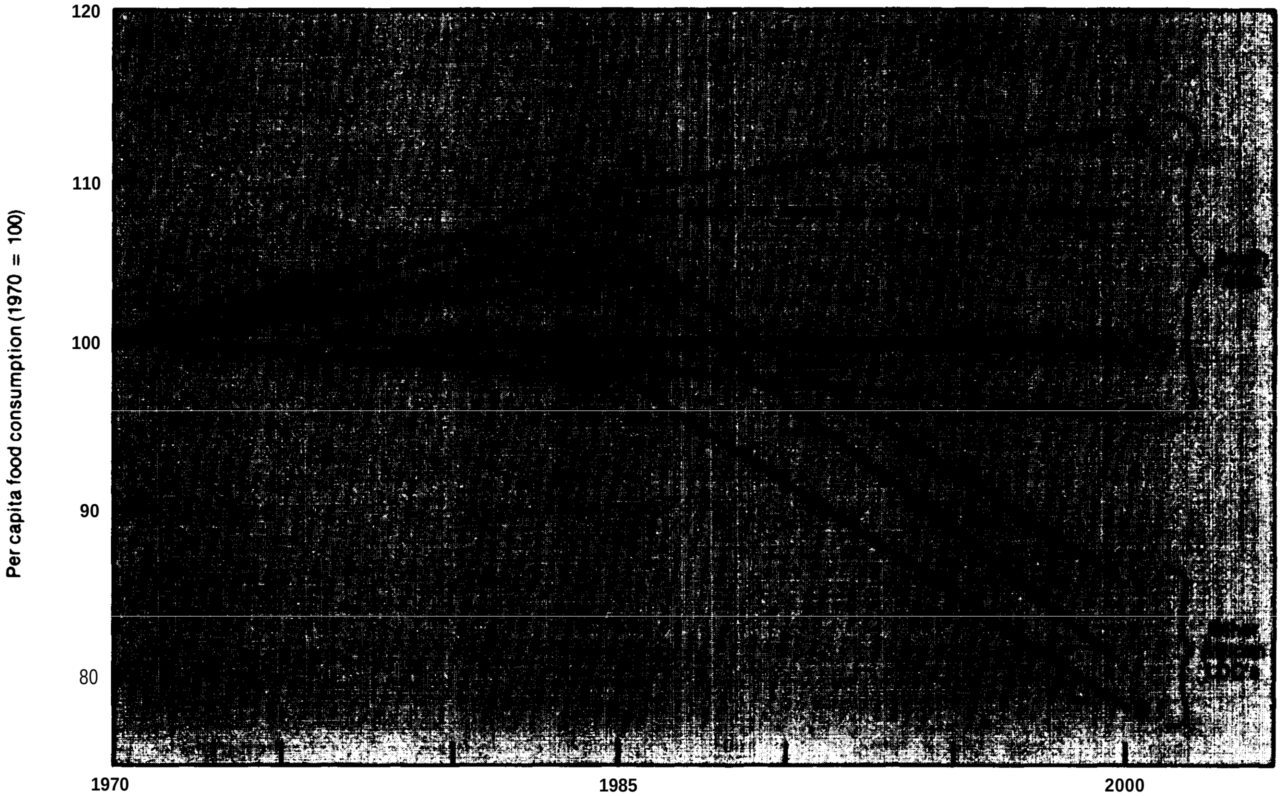
regions, MOIRA considers only one agricultural output—consumable protein—but disaggregates consumers into 12 different income-and~ccupation classes in each of 106 individual nations, which are linked through an equilibrium model of international food trade. This structure allows the model to simulate 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.

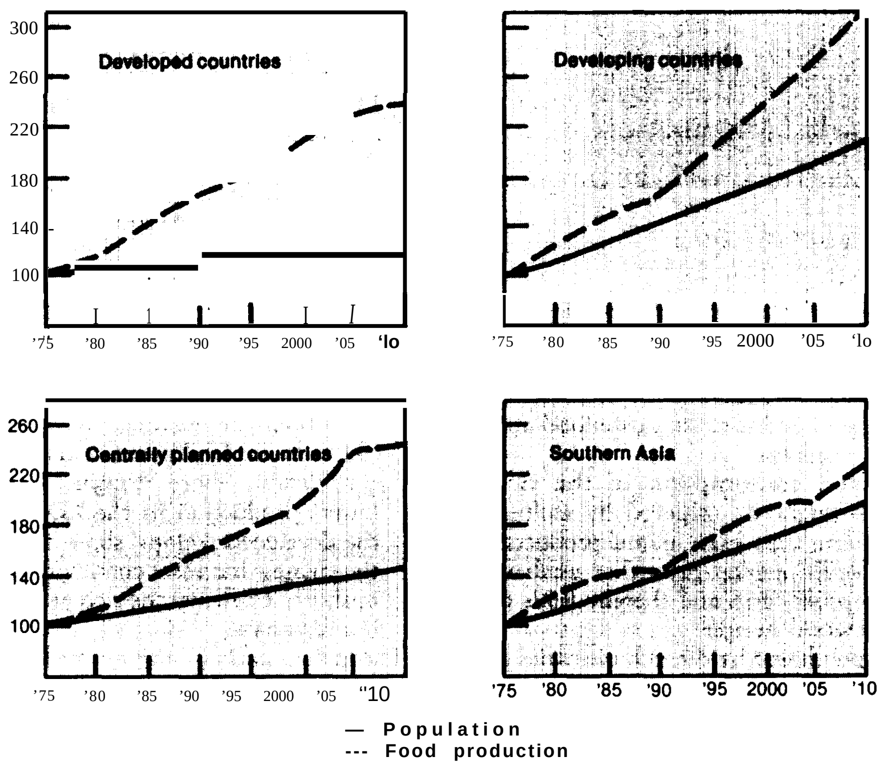
The authors conclude from this last test that "the hunger problem is, to a large extent, a problem of income distribution, " but they are quick to point out the limitations of their model. The general trends it projects are more significant than its precise numerical results, but these sensitivity tests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

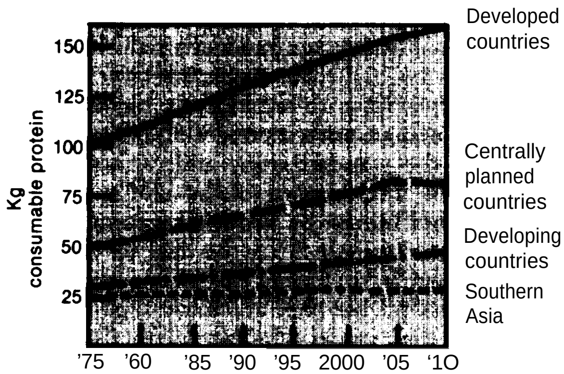
Figure B-n.—Projections of Population and Food Production in MOIRA, Standard Run



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

SOURCE: Extracted from *MOIRA*

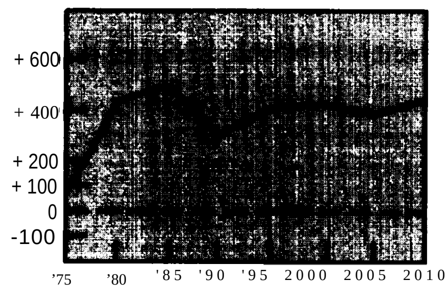
Figure B-12.– Projection of Annual Per Capita Protein Consumption From MOIRA, Standard Run



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

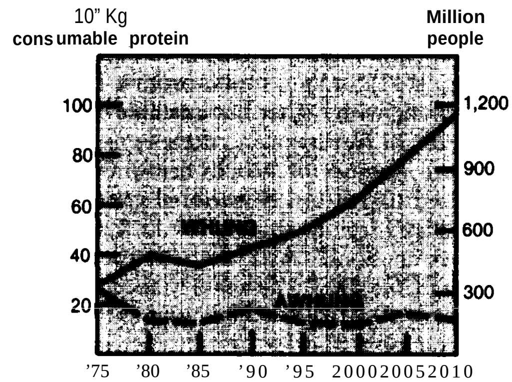


SOURCE: Extracted from *MOIRA,* p. 291.

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

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.

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.

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] Ibid., 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	114	Region	Arable	Land	158		Calories	Protein
	grain		Developed market:	land	productivity	grain	South Asia	120	127
	274		North America	111	194	155	Africa (tropical)	127	140
	livestock		Western Europe (high-income)	100	162	animal	Latin America (low income)	125	143
			Japan	100	269	products	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	522	Not documented		Not documented	140		High	Low
	high growth	high growth				high growth	South Asia	125	75
	185	113				108	Africa (tropical)	164	100
	low growth	low growth				low growth	Latin America	168	117
Global 2000	191 to 201	130	104		160	126		High	Low
	grain	optimistic			to	optimistic	South Asia	113	96
	191 to 198	to			190	104	Other African LDCs.	86	78
	food	215				pessimistic	Latin America	137	111
		pessimistic							
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 in 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 destabiliza-- tion of oil and gas supplies.