World Models: The Bases of Difference

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Differences in global or world models, including dramatic variation in forecasts they produce, have drawn considerable attention. Most analyses in search of the bases for differences focus on general structural characteristics of the models. This article seeks the bases at three interrelated levels: general world view, specific theoretical and structural components, and data and parameter choices. After analysis of various models in these terms, the article describes a world model with sufficient structural and data/parameter flexibility that characteristics of other models can be introduced. Doing so produces behavior which emulates the other models and thereby supports the identification of the characteristics key to behavioral differences.

Introduction

Many social scientists and the broader public interested in global issues greeted with considerable enthusiasm the proliferation of global or world models during the 1970s and early 1980s. Among the broader public, those with policy interests have directed primary attention to the results of forecasts made with the models; many forecasts have been embraced by those with particular policy preferences.

That same strong policy emphasis of the modelers and their followers, and the dramatic differences in forecasts across modeling projects, pose problems for social scientists who want to understand the theory in the models and its linkage to forecasts. Unfortunately, attempts to explain structures of models and differences among them have generally been quite superficial—often even restricted to characteristics such as the time horizon, number of geographic divisions, and identification of major submodels.

This article argues that a desirable approach to understanding the models is to examine them at three interrelated levels: general world views, specific theoretical and structural components, and selected data and parameters. This article is a report on a long-term research project to discover how these three levels interact to shape models and forecasts.

   The approach embodies two elements. First, an analysis and comparison of various models was undertaken to identify key characteristics which appear to explain the differences among their forecasts. This analysis is inadequate by itself, however, since it cannot prove linkage between characteristics and results. The second step was to create a model with sufficient structural and parameter flexibility to emulate alternative world models in an attempt to reproduce the previously identified linkages between model characteristics and forecasts. The creation of a new model in this step, as opposed to the use of existing ones, has two advantages. First, many of the existing models are simply unavailable in the public domain, while those which are available often prove very difficult to install and use. Second, the existing models often do not have the capability (without significant restructuring and reprogramming) to accept the changes necessary to test the effect of structural changes on results.

   One should note immediately that even this two-step procedure cannot prove the linkage between specific features in various world models and forecast characteristics. Models with dramatically different structures can produce identical results. However, if the new model, incorporating apparently key features of the various world models, can generate the behavior of those same models, the suspected linkages will be strongly supported.

   The plan of this paper is a four-stage presentation. I review briefly the most widely known and used models (and some related futures studies) and also summarize some previous efforts to compare and contrast them. I then offer a comparative analysis of the models in order to identify features which appear to account for much of the forecast character. A presentation follows of the model to be used in testing structure/forecast linkages—the model into which the identified features will be introduced so as to determine whether or not they do produce the expected behavior. Finally, I report on the test itself.

The Models

Global or world models obviously predate the 1970s. For instance, work on the Inter-Nation Simulation, a global model with strong political content, can be traced back to 1957 (Guetzkow, 1981), and work on Project LINK, a world economic model, began in the 1960s (Klein, 1976). A new genre of model appeared in the early 1970s, however, capturing public attention with the publication of *Limits to Growth* (Do. Meadows *et al.*, 1972; see also De. Meadows *et al.* 1974, 1976).[1] *Limits to Growth* also became known as the first report to the Club of Rome. Not only was public attention to this model and its report widespread, but other modeling groups were galvanized. In large part as reactions to the Forrester–Meadows work, and then to each other, the following groups or projects prepared models and reports: the Mesarovic and Pestel group (Mesarovic and Pestel, 1972, 1974a, 1974b), which prepared a second report to the Club of Rome; the Bariloche Foundation in Argentina (Bruckmann, 1974; Herrera *et al.*, 1976); the Leontief (1977) or United Nations project; the Systems Analysis Research Unit (SARU) in Great Britain (Systems Analysis Research Unit, 1977); a Japanese group (FUGI) led by Okita (Kaya *et al.*, 1977); Linnemann and his MOIRA group in Amsterdam (Linnemann *et al.*, 1979); and perhaps the only really currently active world modeling effort, the GLOBUS project in Berlin (Bremer, 1984; Cusack, 1984). These are by no means all.

   The results of using these models, for those projects which have issued forecasts and not simply model documentation, have been strikingly different. The Meadows group

argued that the only way to avoid global collapse sometime in the next century is almost immediately to cease growth in both population and the economy. Neither is a likely prospect.

The forecasts of Mesarovic–Pestel or the World Integrated Model (WIM) (Mesarovic and Pestel, 1972, 1974a, 1974b) portray severe regional problems rather than potential global catastrophe. In particular, almost all scenarios (analyses with different assumptions) show potentially large starvation in South Asia. African prospects also often prove dismal. In the North the pressing issues appear to be those of raw materials, especially energy availability and price.

The Bariloche group (Bruckmann, 1974; Herrera *et al.*, 1976) report argues that problems of resources, environment, and even population growth result from inequities in distribution, both internationally and intranationally. Their analyses show that with radical social change (especially egalitarian income distribution), much more optimistic scenarios develop with respect to the provision of food, shelter, and other basic needs.   Interestingly, however, they also point to South Asia as a potential exception and as a long-term problem area. The MOIRA project draws similar conclusions regarding South Asia, thereby demonstrating at least one area of agreement among several different modeling projects.

Leontief's (1977) group portrays a future as generally optimistic as that of the Bariloche Foundation, but without radical social change. Leontief's United Nations project argues, in contrast to Mesarovic–Pestel, that the North–South gap could be closed significantly (in ratio terms) by the year 2000. Moreover, no food or energy shortages are anticipated. Even South Asia may have a fairly promising future.

These model-based reports of the future have been, in large part, responsible for catalyzing not just each other, but a series of less formalized studies. The differences among these latter studies parallel those in the model-based reports and thus deserve some simultaneous treatment. Kahn, a long-time futurist, was explicity critical of the conclusions of *Limits to Growth*. For instance, in *The Next 200 Years* (Kahn *et al.*, 1976), he examines individually the issues of energy, other raw materials, food, and the environment, and rejects completely the conclusions of the Club of Rome reports— that is, Meadows and Mesarovic–Pestel (see also Kahn, 1979; 1982). A report which achieved remarkably favorable publicity and considerable readership in the United States, Simon's *The Ultimate Resource* (1981), was similarly a reaction to the pessimism of the early model-based studies. In contrast, the *Global 2000 Report to the President,* prepared by the Council on Environmental Quality (1981), reiterated the severity of global food, resource, and especially, environmental problems.

All of these studies, whether computer-based or not, generated reviews. There exist even a few comparative analyses, a surprising proportion written by political scientists. Among the comparative analyses are Clark and Cole (1975), Cole (1977), Deutsch *et al.* (1977), Ward and Guetzkow (1979), Hughes (1980), Office of Technology Assessment (OTA) (1982), Meadows, Richardson, and Bruckmann (1982), and Ashley (1983). When surveying the reviews, it is striking to note that approaches tend to fall heavily into one of three categories.

First, frequently (but not as regularly as we might expect), attention is called to the already-noted disagreement among forecasts. There is much of this in the OTA review. It is as if global model forecasts can be reviewed in much the same way that *Business Week* presents a table of the forecasts for next quarter US growth based on ten different econometric models. Most of us look at those tables of econometric forecasts, mentally compute a rough average of the projections, and treat that average as a

reasonable guess. Perhaps world model forecasts can be treated in the same way. Yet we should recognize that there is a qualitative difference between averaging ten numbers which range from 2.5 per cent to 5.4 per cent and averaging the end of the world with a rosy future.

Second, many reviews comparatively examine the structural features of the various models. Table 1 shows a summary of differences by time horizon, geographic treatment, key subunits, and detail of coverage. Meadows, Richardson, and

TABLE 1.   Major global models and their scope

Characteristics	LINK	Forrester-Meadows	WIM	Bariloche
Geography	25 regions (13 OECD and 7 CMEA)	1 world	12 regions (5 subregions of any region)	4 regions (3 LDC regions)
Time horizon	3 years	1900–2100	1975–2025	1960–2060
Substantive areas	Economy structure variable by region Trade (4 categories)	Economy (3 sectors) Population (4 cohorts) Agriculture Resources Environment	Economy (7 sectors) Population (86 cohorts) Energy (5 categories) Food (5 categories) Materials (3 categories) Labor/Education (4 categories) Machinery Aid/Loans Trade (15 categories) Relative prices	Economy (5 sectors) Population and health Food (3 categories) Urbanization/housing Education Trade (3 categories)

Characteristics	Fugi	Leontief	SARU	GLOBUS
Geography	9–15 regions	15 regions	3 strata	25 countries
Time horizon	1975–1985	1970–2000 (10 year increments)	1968–2018 (2 month increments)	1970–2000
Substantive areas	Economy (14 I/O sectors) Mineral resources	Economy (48 I/O sectors of which: Food-4 Mineral, Energy-9 Manufacturing-22 Pollutants-8) Trade (40 categories) Relative prices	Economy (13 sectors, of which: Food-8)	Economy (6 sectors) Government budget Domestic politics International conflict/ cooperation Trade (6 sectors)

Bruckmann (1982) add to this tradition by offering some comparative information, such as disciplinary background, on the modeling groups themselves. They also asked representatives of major modeling groups to answer a common set of seven questions. Although such reviewers are clearly sophisticated, there is an implicit statement in such approaches that the differences in results of model analyses derive from such general structural characteristics. I argue that it is more complicated.

Third, the relative lack of *explicit* political and social content is widely recognized by the modelers as a weakness (Ward and Guetzkow, 1979). Ashley has gone one very important step further by emphasizing the strong *implicit* political and social content. Ashley stresses the commonality of the models—their shared base in 'liberal positivism' or a commitment to a scientific search for a single, objective reality from within the current political and social order. There is, however, at least an apparent contradiction between that supposed similarity of approach and the dramatic diversity of forecasts and prescriptions emphasized here—unless the modelers are just plain poor at their work. The authors of the Bariloche model, which Ashley (1983: 533) notes but does not review, would certainly reject his argument that the 'world modeling community [has] succumbed to the consensually shared order of domination'.

There is obviously value in each of these three approaches to model review, but one cannot help but be left with a feeling that the key differences between the models have not been revealed. One can hardly hope to read a review of such complex models and come away knowing all about them. There may be, however, another approach to comparison which can deepen our understanding.

Key Model Characteristics

A useful approach to analyzing and comparing global models, and future studies more generally for that matter, involves examining them at three levels. At the first level, world models reflect the world views of their creators. The argument here is that those world views, with descriptive and prescriptive elements, vary significantly from model to model. The world views shape strongly the second level, that of theory and submodel structure. World modelers often have several options for the representation of various subsystems within their models or of the linkages among those subsystems. The selection process depends heavily upon world view. The same is true for selection at the third level, that of data or parameters. A considerable number of numerical values within world models have the nature of mathematically inestimable initial conditions which, as constraints or parameters, significantly affect model behavior. Debate among experts over appropriate values leaves the modeler free to choose (or forces a choice).

Is this to say that world modelers begin with an image of the world, and either consciously or unconsciously create their models in that image, presumably shaping their model forecast results in the process? Absolutely. Does this mean that they are being scientifically sloppy in the process? Not necessarily. For instance, it is possible to 'historically validate' models with highly different structures and therefore to produce very different forecasts. The Forrester–Meadows or *Limits to Growth* model (Do. Meadows *et al.*, 1972) was built to run from 1900 to 2100, and successfully traces global aggregate population, economic output, and other key indicators from 1900 to 1970. As a major test of the model, replication of past-current dynamics is not really meaningful. The global crises of food or materials availability or of the environment

which that model forecasts for the 21st century have no counterpart in the historic period. Thus, particular equations, such as that linking environment deterioration to life expectancy, are not really tested in the historic period but are critical in the forecast. The Bariloche model (Bruckmann, 1974; Herrera *et al.*, 1976), which produces very different forecasts, also reproduces well the 1960–1980 period.

In the formulation of the models, all of the projects go beyond the data bases available. Some, like the Leontief (1977) UN model, are better grounded than are others in econometric traditions which demand a solid foundation in data. Instead of incorporating relationships for which data are scarce or uncertain, like the environmental quality/life expectancy relationship of the Meadows model, Leontief leaves many of these out. Forecasts often assume no relationship. For instance, the UN model contains no direct constraint upon economic growth from depleting ultimately available fossil fuel resources. Such a relationship would be almost impossible to estimate empirically. Leaving it out, however, resulted in a forecast of 5.2-fold growth in global consumption of petroleum between 1970 and 2000 (Leontief, 1977: 5). It would be difficult to find a geologist (or, for that matter, an economist) who believed that were possible.

World Views

In the absence, then, of adequate data and theory or precedent, global modelers must make many choices about structure and parameters which can most generously be characterized as intelligent guesses. These will not, however, be random selections from the pool of available options. Many selections will be shaped strongly by world views and by the forecasts for global developments which the modeler expects (and wants) the model to produce.

One of the key characteristics of the model construction process which allows such freedom in selection of structural and parameter options is its iterative nature. No modeler of complex systems constructs a model and then, when it is all done, uses it to make forecasts. It would produce nonsense. Instead preliminary forecasting and review of model behavior is an integral aspect of submodel development and of the process of linking components. If the behavior in this 'sensitivity analysis' is not 'right', the structure will be revised or 'tuned'. Forrester speaks highly of the importance of producing 'counterintuitive' results—that is, results which are not predicted or anticipated by the modeler. They are new insights, requiring explanation, into the workings of a complex system. Most initially 'counterintuitive' results are discovered by the modelers to be errors in programming, such as feedbacks left out which in hindsight are clearly important, or in poorly specified relationships. Once these are corrected, the result may disappear. This iterative process eliminates results counterintuitive to the modeler's world view. But what about those which are counterintuitive to the views held by you or me? Very seldom do modelers intimately involve critics of their images of the world in the development process.

An analysis of world models and futures studies suggests at least two important dimensions of world views which shape model structure and behavior. The first dimension is political economy. The second dimension I call political ecology. Whereas political economy treats the actual and desirable relationships between the political and broader social system and the economy, political ecology extends the linkage of politics to the natural and biological environment. Although it can be traced 2000 years as a dimension structuring world views (Breckling, 1974), it is less well established in current thinking than political economy. Work by Ophuls (1977),

Pirages (1978) and Daly (1980), are among the best recent examples.

Having identified the two dimensions, I now position various perspectives along the dimensions. The polls of the political ecology dimension are labeled classical liberal and radical. An intermediate position is identified as internationalist. Internationalism characterizes individuals who attribute greater importance than do classical liberals to the current and traditional political linkages among First and Third Worlds in analyzing development problems, but who fall short of the radical position that such relationships largely dictate development patterns. For instance, an internationalist would support foreign aid increases, while a classical liberal might reject them as market-distorting and inefficient, and a radical might reject them as political control instruments. For opposing view points equivalent to classical liberal and radical on the political economy dimension, I shall use the terms modernist and neo-traditionalist; they could also be called no-limits and limits, respectively. No intermediate position is identified. This article will not attempt to spell out the differences between the positions on these two world view dimensions or to justify the categories. The political philosophical roots and the current applicability of the perspectives are traced in detail in Hughes (1985).

There are, of course, many variations on these simple world view themes. Figure 1, combining the two dimensions, suggests the degree to which world models and future studies differ, and the degree to which the two dimensions help us classify them. Well-known studies are placed into the appropriate quadrant relative to the two intersecting dimensions. A similar analysis appears in Miles (1978).

Some studies are particularly easy to place, largely because the authors obviously see debates about the present or future in terms of these or very similar dimensions, and explicitly place themselves in contrast to other world views. For example, Simon's (1981) book is an almost perfect example of a classical liberal/modernist view, even more so than the often similar work of Kahn (1976, 1979, 1982). Similarly, the Bariloche world model project (Herrera et al., 1976) effectively self-classifies itself

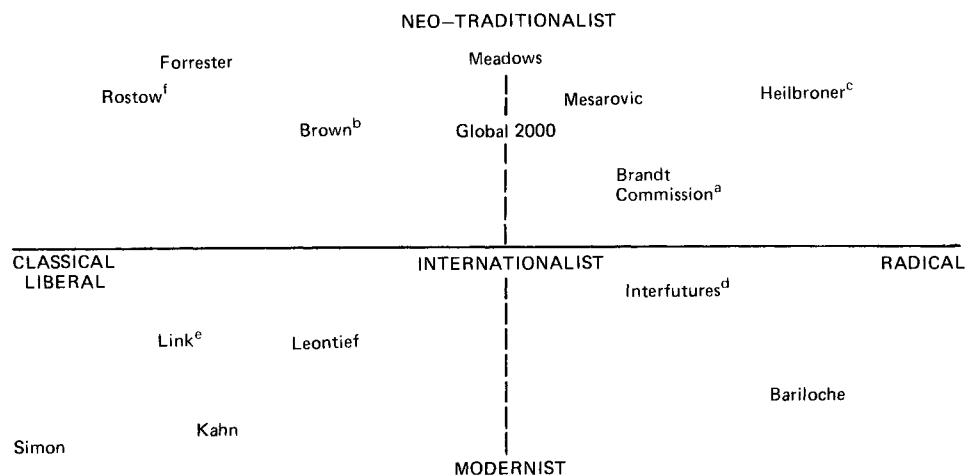
FIG. 1. World view dimensions in world models and futures studies. [a]Brandt, W. (1980); [b]Brown, L. R. (1981); [c]Heilbroner, R. L. (1975); [d]Interfutures (1979); [e]Klein, L. R. (1976); [f]Rostow, W. W. (1978).

radical/modernist. The authors do so by denying any real resource or environmental limits and simultaneously calling for explicitly radical social/political change. These are positions they articulated before they began work. The *Global 2000* study (Council on Environmental Quality, 1981) is a fairly clear example of the internationalist/neo-traditionalist perspective.

Other reports are much more difficult to classify, and the author(s) might well dispute the placements made here. In some cases the thinking of the forecaster(s) appears almost completely dominated by one world view dimension. For instance, *Limits to Growth* (Do. Meadows *et al.*, 1972) is clearly at the neo-traditionalist or limits extreme on the political ecology dimension. But it devotes very little attention to the issues of the political economy dimension. The study does not prescribe with any specificity policies or changes in structures to take the world from growth to stability.

There is still another factor which makes difficult the classification of some studies on the world view matrix of Figure 1. There are, of course, more than two dimensions in thinking about the future, even though we have chosen here the political ecology and political economy dimensions as structuring thought most often and clearly. In particular, however, there is a difficulty with respect to classifying neo-traditionalists by political economy perspective which does not have a parallel at the modernist end of the political ecology dimension. Part of this is, as suggested earlier, that many neo-traditionalists seem to have given little real thought to the nature of desirable political institutions and their relationship to the economy.

Yet there is more. Many neo-traditionalists reject all three of the political economy perspectives outlined here. They perhaps most ardently reject the classical liberal view, seeing it as a 'do-nothing' and 'growth-above-all' approach in the face of massive challenges to human systems. The policies of internationalists or reformers, such as foreign aid, technical assistance, and commodity price stabilization schemes, are also often seen as inadequate. Yet the collectivism and authoritarianism which they perceive as associated with the radical view also repel many neo-traditionalists.

The classification of world views in Figure 1 must be considered a rough one at best, but as we shall see, it can prove very useful in understanding model structures.

Theories and Models

The decisions by which a world view becomes translated into a specific world model structure are numerous. A real understanding of comparative model structures requires that we examine some of the more important decisions. Table 2 organizes some of the points made in this section and the next with respect to selected emphases of world views.

Population models are the least controversial area of world modeling. Population forecasts over a 20–30 year time horizon vary little, even when quite dramatic changes in fertility or mortality are hypothesized. Also, almost all population forecasts use some variation of the same basic technique: cohort–component analysis.

Yet world model approaches to population submodels do vary dramatically. Leontief (1977) takes the classical liberal view that population growth is responsive to economic change (through individual self-interest calculations) rather than to policy and does not represent population at all. Bariloche (Herrera *et al.*, 1976) arrives at a similar conclusion from the radical perspective, but although the authors believe that population growth rates depend on incomes and income distribution, not on family planning programs, the model does include a population subsystem. This is because income distribution issues and labor productivity are central to the Bariloche view.

Both the Meadows (1972, 1974, 1976, 1982) and Mesarovic–Pestel (1972, 1974a, 1974b) models accept the neo-traditionalist premise that population control is a central issue and the internationalist belief that explicit government programs can in important ways assist economic factors in lowering fertility rates. Those models include family planning programs as important exogenously manipulated scenario variables.

With respect to economic submodels, a central structural issue is whether the model is demand- or supply-driven. Both Leontief and Bariloche are predominantly demand-driven models, a feature consistent with modernist views, since modernists minimize supply-side constraints. In Leontief's case a forecasted demand vector and an inverted I-A (identity minus technical coefficient) matrix are used to compute supply requirements. In Bariloche (the most clearly prescriptive of all the models) a criterion function based on maximizing life-expectancy directs the model to allocate goods and services to sectors like education, food, and housing, so as to optimize growth in life-expectancy. The Bariloche model even represents a satiation effect on the demand side; specifically, once basic caloric needs are met, the optimizer allocates no additional resources toward food provision. In contrast, both the Meadows and Mesarovic–Pestel models are essentially supply-driven, a feature consistent with neo-traditionalist world views. With the exception of food availability they show little concern with the pattern of goods delivered to final consumers or with distributional issues (radical concerns). Nor is there any assumption of satiation in goods demand which might ease pressures for continued resource inputs. The supply-side models can and do treat explicitly the implications of increasing resource scarcity for capital efficiency, a major concern of neo-traditionalists.

Another structural distinction among economic submodels is the nature of the production function. The Meadows model uses a Harrod–Domar function which specifies only capital as a factor of production. In such models population increases only serve to lower average incomes, they do not contribute to increased supply. Such an approach is again consistent with neo-traditionalist views. The Bariloche model consciously adopted a Cobb–Douglas form in which labor availability also contributes to total output. It is actually surprising that they did not go one step further and make labor quality a factor. Mesarovic–Pestel uses both function forms, but relies overwhelmingly on Harrod–Domar.

International trade is an exceptionally difficult area to model, especially the representation of structural change in global trade patterns. Thus, none of the models treats it satisfactorily. The Meadows group simplified the world to one region, eliminating both the potential benefits of trade claimed by liberals and the potential dependency problems seen by radicals. Most United Nations (Leontief) model runs were made without restrictions on balance of payments deficits in LDCs. This leads to incredibly large deficits in some cases. For instance, *annual* deficits in medium income Latin America equal 27 per cent of GDP by 2000. Such a forecast seems to be an implicit statement that such large levels of indebtedness pose no problems if the market allows them to accrue. The Mesarovic–Pestel model always puts constraints on indebtedness, generally resulting in slower LDC growth. But the authors use increased foreign aid in scenarios to limit the constraint, obviously an internationalist orientation. At the other extreme from Leontief, the Bariloche model forces all regions towards balance of trade equilibrium, reflecting a real concern with external dependence.

In the area of energy and raw materials, structural approaches again vary

dramatically. Whereas economic model differences often reflect political economy positions, resource treatment reflects primarily political ecology. In *Limits to Growth* there is an absolute resource availability limit, although it can be pushed back in scenarios. In Mesarovic–Pestel some categories of energy are subject to such absolute resource constraints, but others are renewable or eternal (specifically nuclear and hydro). Neither Bariloche nor Leontief represent ultimate availability of any resources explicitly.

With respect to agriculture, Meadows and Mesarovic–Pestel rely upon a yield function which posits decreasing marginal returns at greater levels of inputs such as fertilizer. Yield eventually peaks in such functions. Kahn's (1976) modernist report relies effectively on indefinite extrapolation of linear or non-linear historic gains. The Leontief model also puts no explicit constraints on yield growth. Bariloche, like the neo-traditionalist models, uses a saturating exponential function, but adds further technologically-based yield increases.

Data and Parameters

It is slightly more difficult to verify that initial conditions and parameters reflect world views, because values used by the various projects are poorly documented and even when available they often arise in equations of such different form as to be incomparable across models.

Some examples serve to illustrate the potential, however. In the area of energy, an important parameter is the assumption made for ultimately recoverable oil or gas resources (if the model structure makes that a binding constraint). Mesarovic–Pestel base such assumptions on conventional resources only; for instance, the oil figure is about 1.5–2.5 trillion barrels globally. Kahn, in his non-model based report (1976: 63), suggests ultimate petroleum resources over 10 times larger. To the degree that renewable resources are potentially available, the Mesarovic–Pestel (1972, 1974a, 1974b) model puts effective costs on them considerably higher than current oil prices. Kahn suggests costs considerably lower.

Because each of the models recognizes the importance of food, parameter values in that sector are most nearly comparable. Consider, for instance, differences in ultimate land availabilty for agriculture. The *Limits to Growth* (Do. Meadows *et al.*, 1972) model posits an ultimately available arable land figure of 3.2 billion hectares, a figure initially presented by the United Nations' Food and Agriculture Organization and widely adopted by futurists. However, they assume that continued population growth and pressures for residential, commercial, and industrial use of that land will result in steadily declining amounts available for agriculture. Interestingly, the extra land needed for additional people is based on research done in Western US counties, areas hardly known for high population density. By the middle of the next century the anticipated result is less than 2 billion hectares actually cultivatable. Bariloche (Herrera *et al.*, 1976) uses the same 3.2 billion hectare initial figure, but assumes that it all could be made available given investment in land not now cultivated.

Other agricultural figures are even more directly comparable. Bariloche says that the cost of developing raw land will increase from the current $1200 per hectare to a maximum of $6000 (Herrera *et al.*, 1976: 58). The Meadows group agrees roughly with current costs, but assumes development costs will grow to $100,000 per hectare as undeveloped land becomes scarcer (Meadows *et al.*, 1974: 291). Similarly, the Meadows group argues that a doubling in global yields per hectare would require a 6-fold agricultural input increase, including fertilizer (Meadows *et al.*, 1974: 305). The

Leontief (1977) model achieves such a doubling between 1970 and 2000 with less than a four-fold increase in fertilizer and an apparently lesser increase in other inputs (e.g., capital). A calculation using the Bariloche technical report (Bruckmann, 1974: 104–106) suggests that the model allows a yield doubling with about a 1.5-fold increase in fertilizers. The difference between a six-fold assumption in *Limits to Growth* and a 1.5-fold assumption in Bariloche is only part of the story. In the Meadows model, yields are, in addition, negatively affected by the growth in pollution. In the Bariloche model, food availability in LDCs is further increased by over 20 per cent through the assumption that after-crop harvest losses will drop from 30 per cent to 10 per cent (the level in middle-developed countries) over 20 years. Such an assumption has no economic cost in the model.

In the economic submodels a key assumption is savings rate, or the portion of current production reinvested in capital formation. In Mesarovic–Pestel, that rate was constant, or even decreasing, in most scenario runs. In Meadows, savings appear generally to be constant or decreasing (as the model directs an increasing portion of total investment to resources). But in the Leontief (1977: 7) model the basic- or reference-run assumption was an increase from 20 per cent in 1970 to 41 per cent in 2000 for the Middle East and Africa, from 17–20 per cent to 31–33 per cent for Latin America and from 15 per cent to 23–25 per cent in non-oil Asia and Africa. In Bariloche's (Herrera, 1976: 89–94) base case the level increased from 18.2 per cent to 25 per cent in Latin America, from 15.1 per cent to 25 per cent in Africa, and from 16 per cent to 25 per cent in Asia. These differences in investment rates have dramatic consequences for growth.

In defense of these modeling reports, none of the widely differing data or parameter values were chosen without basis. Almost all are justified in reports of various experts. But selection was obviously filtered by world views.

A General Model

The previous section identifies key features of various models—features which appear to explain many of the differences in forecasts by those models. The next section tests those identifications by introducing the features into a model constructed in large part for that purpose and seeing if various forecasts are replicated. The model is called International Futures (IFs). The name conveys the if–then nature of forecasting with such a model and the IFs documentation stresses the three levels of if–then statement presented here: world views, theory and submodel structure, and data and parameters (Hughes, 1982a, 1982b). The documentation describes in detail the model structure, including all equations, and a complete list of parameters. The discussion here can be an overview only.[2]

IFs is a general model in two respects. First, it incorporates, at least in simplified form, many key features from the generation of world models discussed above. For instance, it uses the detailed cohort–component demographic structure of Mesarovic and Pestel's (1972, 1974a, 1974b) World Integrated Model, has the human needs and quality of life indicators of Bariloche (Herrera *et al.*, 1976), the economic equilibrium structure of SARUM (Systems Analysis Research Unit Model, 1977), and the input–output matrix of Leontief (1977) (in each case, simplified). Second, the model has an interactive structure extending to nearly every parameter—that is, a user can alter parameters at a terminal and produce new forecasts in a matter of seconds. Some parameter choices can decouple model subunits, sever relationships, or remove

variables from equations, thus effectively changing model structure. Both the structural generality and the parameter flexibility are important to the analysis undertaken.

IFs is about the same size in terms of equations and variables (2000) as earlier models (much larger than Meadows, a bit larger than Bariloche, about the same as Leontief, and smaller than Mesarovic–Pestel). It represents the world in ten geographic regions: the United States, Western Europe (including Yugoslavia), the Rest of the Western Developed World (Japan, Australia, Canada, etc.), Eastern Europe, the Soviet Union, non-OPEC Latin America, Africa (except South Africa and OPEC members), OPEC, South and Southeast Asia (minus Indonesia) and China (plus other communist Asia). The model is initialized in 1980 and runs indefinitely in one-year (or longer) cycles. Normal forecast horizons are 2000 or 2025.

IFs has five major submodels: population, economy, energy, agriculture, and trade/international finance. The population submodel is sketched in Figure 2. The structure is termed cohort-component, which at its simplest level is an accounting scheme. Sixteen five-year cohorts and a larger cohort for individuals over 70 years of age divide the population. Births are added to the bottom of the population age distribution, deaths subtracted from each cohort, and the cohorts advanced in age. The controversial elements center on the functions which alter fertility and mortality distributions.

In IFs, fertility and mortality distributions are responsive (if the user desires) to Gross Domestic Product (GDP), income distribution, and posited family planning programs. The Gini index is used as a measure of income distribution, but is changed from initial conditions only exogenously, because it is so dependent on political and social structures. In addition, mortality depends on the level of starvation, in turn a function of the balance between calorie availability (computed in the agricultural submodel) and calorie needs. Mortality depends further on government health expenditure levels and scenarios of model users (for example, some have wanted to ask what-if questions concerning breakthroughs in medical technology which would
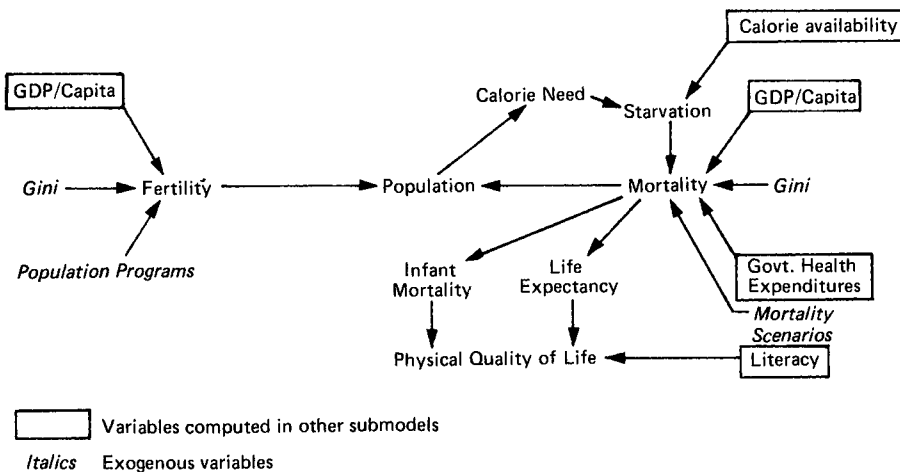

FIG. 2. Overview of the population submodel.

dramatically reduce mortality).

Average life expectancy at birth, infant mortality rate, and literacy allow computation of the Overseas Development Council's physical quality of life measure. This is a simple index with a range from 0 to 100; it weights the three inputs equally.

All variables in Figures 2–6 designated 'exogenous' are given values in the basic parameter load and need be specified by the user only when a change is desired. All figures are simplifications of the complete model.

Figure 3 presents an overview of the economy submodel. It represents the economy in five sectors: agriculture, materials, energy, industry, and services. It is a model of economic equilibrium having fairly complete demand *and* supply sides. The supply side uses Cobb–Douglas production functions (easily simplified to Harrod–Domar if desired by the user). Disembodied technological progress for both capital and labor can be exogenously changed by the model user. Also affecting productivity are two feedbacks from elsewhere in the model: changes in energy prices are directly linked to capital productivity (e.g., premature obsolescence), and literacy is directly linked to labor productivity. Both of these feedbacks can be eliminated with parameter switches. An A-matrix is used to compute intersectoral flows and production for final demand from gross sectoral production.
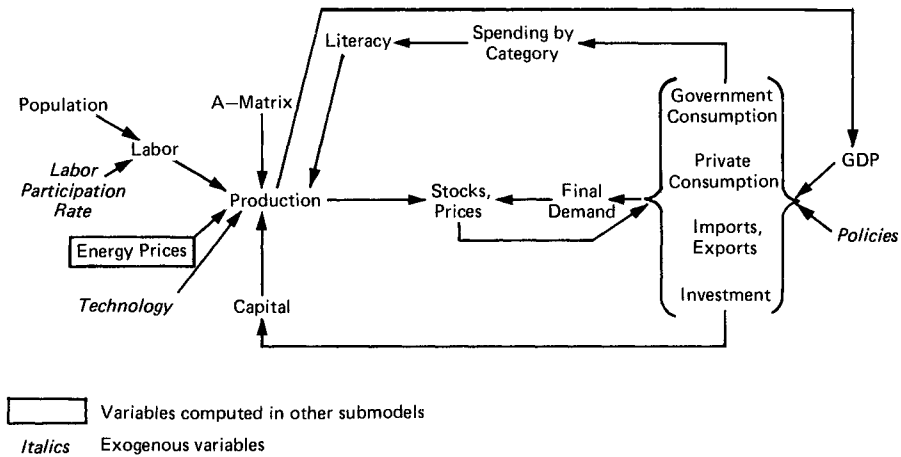

FIG. 3. Overview of the economy submodel.

On the demand side of the model, trade-offs among various expenditure components (government consumption, investment, private consumption) are recognized. The goverment spending/investment linkage is subject to policy choices. Total government consumption is directed toward military, health, and educational categories by the model user. Literacy depends on educational spending levels. Total private consumption is divided into sectors by Engel curves.

The balance between production and final demand is struck using stocks as a temporary buffer, but with relative sectoral price change guiding longer-term equilibrium-seeking behavior. Prices feed back to all aspects of final demand, affecting, for instance, consumers' choices among sectors, import and export levels, and investment levels and patterns. The distinctions among market economies and

centrally planned economies, with their much lesser use of pricing mechanisms, are obviously underdeveloped within IFs. The equilibrium-seeking predisposition repre-sented here, however, is at such a high level of aggregation that the distinction between pricing and central planning mechanisms is not so important. It is also possible completely to exogenize price in any or all sectors, which results, of course, in supply/demand disequilibrium to be addressed by other mechanisms (e.g., investment direction).

The agriculture and energy submodels provide alternative calculations of supply, demand, trade, and price in the food and energy sectors which, because of their greater detail, normally supplant those in the economy submodel, but the user can decide not to do so by a single parameter change in each case.

Figure 4 shows the general outlines of the energy submodel. It represents production, consumption, trade, and pricing of four energy types: oil-gas, coal, nuclear, and renewable (hydro, wood, solar, etc.). It explicitly represents known reserves and ultimate resource estimates of the fossil fuels which will, unless the user opts otherwise, eventually constrain energy production in those categories. The sub-model actually distinguishes between ultimately recoverable resources (exogenously specified if desired) and known reserves at any given point. Reserves are augmented by discoveries and diminished by production.
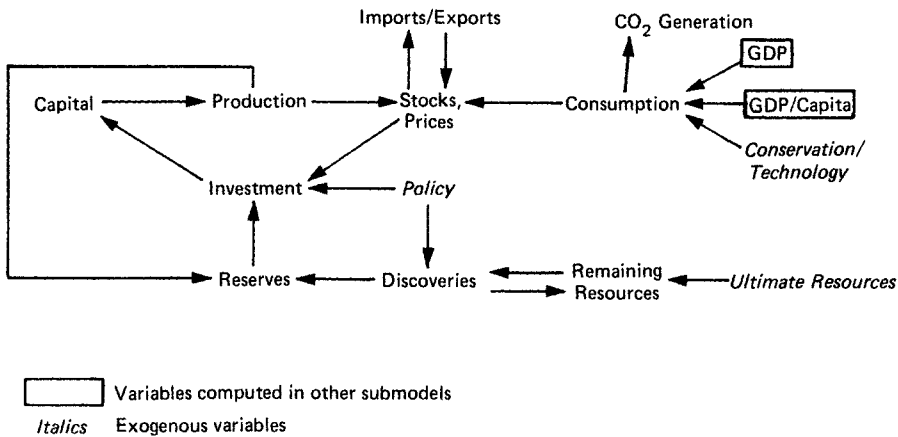
FIG. 4. Overview of the energy submodel.

Capital investment levels are critical to energy production capabilities; energy investment needs compete with those in other sectors. Even when the energy and agriculture submodels supplant these same sectors in the economy submodel, all accounting identities are maintained.

Total energy consumption is linked to both economic activity and prices—estimates of appropriate elasticities vary greatly and the user can override those in the basic parameter load if desired. Relative demand for the energy forms is ultimately responsive to their cost, although again the user can override this and impose a particular consumption pattern. The cost of fossil fuels varies inversely with remaining resources and change in the future cost of nuclear and renewable energy forms is

exogenously specified.

The core agriculture submodel can be seen in Figure 5. The full agriculture submodel incorporates production, consumption, trade, and pricing of three food types: crops, livestock, and fish. It separately represents crops used for food, livestock feed, and industrial purposes (e.g., alcohol production). The submodel distinguishes between crop, grazing, forest, undeveloped, and urban/industrial land uses. On the production side, crop production is the product of land under cultivation and yields per hectare. Yields are a function of labor, capital, and technology. Investment is directed to land or short-term inputs on the basis of relative rates of return. The overall level of investment depends on food prices, and is competitive with investment elsewhere in the economy, but policy can favor or downgrade the sector.
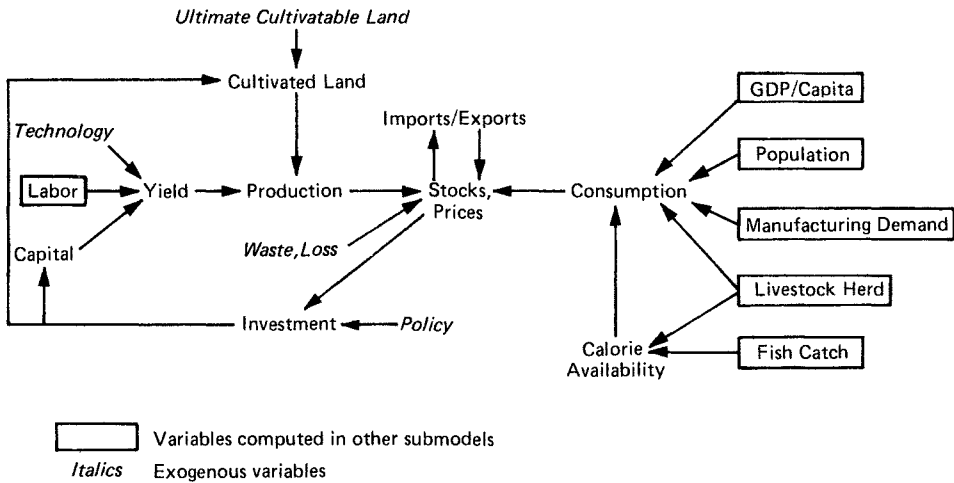

FIG. 5. Overview of the agriculture model (crops only).

Crop consumption is primarily income responsive (from the economy submodel), but it also depends on industrial and livestock demand for crops. Livestock herd size and meat consumption (not shown) depend on income levels unless the model user decides otherwise.

The international linkages of IFs are currently restricted to trade and aid/investment. Those linkages can be seen in Figure 6. Trade is represented in terms of gross trade (imports and exports separately) by region, and a pooled-trade algorithm reconciles global import demand and export capacity. Debt levels of regions for which negative current account balances persist restrict import demand of the debtor, if the user desires. In addition a user can exogenously shift terms of trade for the less developed regions, either positively or adversely. Normally, however, trade terms depend on endogenously computed relative prices and trade patterns. Aid is based on percentages of the GDP of donor regions.

As this brief structural overview suggests, most of the features hypothesized above to be critical to the forecasts of other models (see Table 2) exist in IFs and can be used, circumvented, or replaced by alternatives. Thus, the IFs model is in many ways structurally able to emulate other world models.
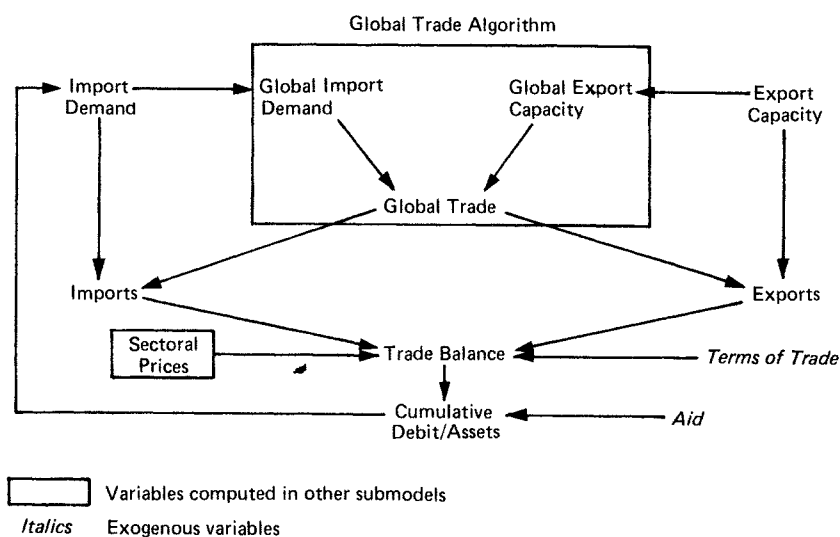
Global Trade Algorithm

Variables computed in other submodels
Italics   Exogenous variables

Fɪɢ. 6. Overview of the trade and international finance submodel.

The Test

Emulation of earlier world models is exactly the intent of this section. Earlier sections of this article identify *probable* bases for differences in the forecasts of world models and describe a model into which many of these bases can be introduced. We now want to see if actually doing so will result in forecast differences like those reported in the literature.

Eight different analyses were made with IFs. Because of the IFs program structure, some parameter changes can, as sketched in the previous section, effectively alter basic submodel structures. All parameter changes were made to be consistent with one or another of the world views presented above, and/or the model(s) structured around

TABLE 2.   Selected emphasis of world views in key issue areas

	Classical Liberal	*Internationalist*	*Radical*	*Modernist*	*Neo-Traditionalist*
1. Population	Economic Growth	Policy	Income Distribution	—	Policy
2. Economics	Investment Rates	Aid, NIEO Policies	Human Capital Terms of Trade, International Debt	Demand Growth	Supply Constraints
3. Energy/ Raw Materials	—	—	—	Technological Growth, Non-fossil Energy	Absolute Resource Limits
4. Agriculture	—	—	—	Technological Growth	Declining Marginal Returns, Limits on Land

them. In some cases the magnitude of the parameter values appeared unreasonable to me personally, but an effort was made to maintain them within the range suggested by the futures studies and model reports discussed.

The alternative analyses developed by IFs program runs have actually been tailored more to general world views than to specific models. There are two reasons for this. First, a major argument of this article is that *world views generally, not a handful of specific assumptions, shape model structures and forecast results.* Second, and more practically, it is unrealistic to argue that IFs can emulate the specifics of each model; all that is claimed here is a general reproduction of key characteristics, especially those which suggest an underlying world view.

The resulting eight scenarios and their basic assumptions are as follows:[3]

1. *Reference or Base.* No parameter changes were made in this case. The model was simply initiated with standard parameters in 1980 and allowed to run until 2025. The model will project forward indefinitely, but was not created to be used past 2050. Forecasting until 2025 allows examination of a 45-year period over which major demographic and energy system transitions occur. Although shorter than the forecast period of Meadows (1900–2100), it is equal to or longer than that of the other model reports. The basic model structure and the reference case parameters produce an extrapolative, no-surprises forecast. Results are generally near the central tendency of those from a wide range of forecasts (which should *not* automatically give them any greater credibility).

2. *Liberal.* This scenario emulates to a considerable degree the structure and assumptions of the Leontief (1977) model. For instance, because that model does not represent the possibility of hard constraints from energy (or other raw materials) or from food availability, the linkages between those submodels and the economy submodel are severed (the economy submodel structure for the other three sectors is extended to agriculture and energy). Since the Leontief model scenarios generally do not constrain LDC growth by cumulative balance of trade deficits, that constraint is eliminated from IFs. As noted earlier, the Leontief report calls for considerable growth in savings and investment rates in LDCs, exceeding those in the reference run of IFs. For example, in the IFs reference run, savings levels increase in Latin America from 21 to 25 per cent of GDP. In the liberal run this increases further to 28 per cent, which is still a bit short of Leontief's 30 per cent prescription. In addition, labor participation rates for LDCs (the percentage of population employed) is held constant in the IFs reference run (an overly conservative assumption). In the liberal run they increase gradually to more developed country rates by 2025.

3. *Radical.* All eight scenarios tend to blur somewhat description and prescription. The radical scenario, however, is the most clearly prescriptive in that it requires assumptions of fundamental changes in economic structures, and implicitly assumes changes in political structures not represented. The implementation in IFs assumed both national and international changes. Internationally, terms of trade gradually shift in favor of LDCs. The shift increases export value for the poorest LDCs by 20 per cent over 20 years, relative to the reference case. In addition, military expenditures gradually fall to 10 per cent of total government expenditures in all regions, a sharp drop from the nearly 50 per cent levels of military expenditure in Latin America and Asia. Increases in education and health spending offset the reductions. Such expenditures are not represented in the Bariloche (Herrera *et al.*, 1976) model. This scenario further assumes a transformation of LDC income distribution patterns comparable to that of the Bariloche model. Specifically, the Gini index for income

was forced to 0.2 (from 0.48 in Africa and 0.39 in Asia) for all LDCs. Like Bariloche, crop losses after harvest were reduced by 20 per cent over 20 years. Again like Bariloche (and the liberal scenario), considerable increases in local savings and investment are assumed. The effect of many of these changes is reinforced by explicit increases in the labor participation rate and labor force efficiency in the scenario.

4. *Neo-traditionalist*. The Meadows model and report (Meadows *et al.*, 1972, 1974, 1976, 1982) served as bases for this scenario. The major changes from the reference run are to incorporate considerably more pessimistic assumptions about ultimate energy resources and about technological progress in agriculture. In addition this scenario assumes somewhat more severe economic penalties for higher energy prices than does the reference case, extending to a slow drop in the efficiency of capital use. Because the IFs model does not have an explicit linkage between malnutrition or starvation and labor productivity, some loss of labor productivity is assumed due to the appalling collapse in food availability and increase in starvation. Similarly, a significant drop in international credit availability is posited in response to the slow economic growth of this scenario.

5. *Modernist*. No existing world model clearly captures the modernist world view, so the work of Kahn (1976, 1979, 1982) served as a model for this scenario. Ultimate energy resource assumptions are relaxed to the point that they posed no constraint in the 45-year period. Agricultural technological progress is assumed to provide yield increases a full one per cent per year higher than in the reference case. As in the radical scenario, crop losses are assumed to drop. Technological progress enters the economy directly by a gradual increase in capital productivity, coupled with an investment increase in all regions comparable to that of the liberal scenario.

6. *Modernist-Liberal*. 'Pure' world views appear in actual models less frequently than do mixed cases. For instance, the Leontief report is more strictly modernist-liberal than simply liberal. This scenario combines assumptions in the two outlined above—that is, it incorporates the parameter changes of both earlier scenarios. In this and subsequent mixed cases, when the two scenarios both require change in the same parameters, and in the same direction, the new value is that which deviates more from the reference case. If the two scenarios require change in the same parameter, but in opposite directions, no change was made.

7. *Modernist-Radical*. Similarly, the Bariloche model fits better here than in the radical category alone. This, too, is a simple combination of assumptions.

8. *Optimist*. For fun, rather than to prove any particular point, this scenario combines assumptions from the modernist, liberal, and radical scenarios, so as to maximize world economic growth and to minimize the North-South economic gap. Given that its liberal and radical parents are hardly wedded, it could have been given another name.

A common set of indicators captures the differences among these eight scenarios. Table 3 shows eight summary global indicators. The values for the reference case are given for the years 1980 and 2025; those for all other scenarios are provided for 2025 only, since the initial year is always identical.

The first variable is world economic product in trillion constant (1980) dollars. The second is the population-weighted ratio of per capita GDP in the five more developed regions of IFs (the United States, Western Europe, Rest of Developed Market Economies, Eastern Europe, and the USSR) to the five less developed regions (Latin America, Africa, OPEC, Asia, and China). The third is the ratio of the Overseas Development Council's physical quality of life index (PQLI) for the same two sets of

TABLE 3.   Results of scenario runs with IFs for year 2025.

Scenario	World Product (in trillions of 1980 dollars)	Developed/ Less Developed Per Capita GDP Ratio	Developed/ Less Developed PQLI Ratio	World Population (in billions)	Total deaths by starvation 1980–2025 (in millions)	Global CO_2 Increase from pre-industrial levels (in percent)
Reference						
1980	11.4	12.6	1.41	4.45	0	12.3
2025	33.8	12.5	1.31	7.90	16	41.7
Liberal	42.4	5.8	1.11	8.20	0	49.3
Radical	51.7	7.2	1.09	8.21	0	46.4
Neo-Trad	10.4	10.6	1.52	5.00	2270	34.2
Modernist	38.6	10.2	NA	8.05	0	49.4
Mod-Lib	44.2	5.6	1.10	8.20	0	57.5
Mod-Rad	57.2	6.1	1.07	8.19	0	56.0
Optimist	61.2	4.2	1.08	8.17	0	61.7

Scenario	World Energy Price (in 1980 dollars/ barrel of oil equivalents)	World Grain Price (1980 dollars/ kilo)	Gross Domestic Product per Capita (in thousands of 1980 dollars)			
			U.S.	Africa	Asia	Latin America
Reference						
1980	31	0.16	11.6	0.43	0.27	1.58
2025	116	0.23	26.1	0.64	0.45	2.62
Liberal	103	0.18	23.6	0.95	1.09	3.40
Radical	128	0.19	39.1	1.63	1.18	5.15
Neo-Trad	239	0.31	10.0	0.25	0.11	0.50
Modernist	NA	0.13	28.0	0.88	0.84	3.00
Mod-Lib	24	0.10	24.3	1.06	1.22	3.62
Mod-Rad	49	0.11	40.4	2.31	1.83	5.69
Optimist	34	0.09	33.7	1.92	1.85	5.43

regions. The fourth is global population in billions and the fifth is cumulative global starvation deaths over 45 years, in millions. The sixth indicator in Table 3 is the percentage increase in atmospheric carbon dioxide (CO_2) relative to pre-industrial levels. The seventh is the world energy price per barrel of oil equivalent in constant dollars, and the final global indicator is the world grain price, in constant dollars per kilogram. Table 3 also shows the gross domestic product (GDP) per capita for four selected regions.

In the *reference* case the global economy grows from 11.4 to 33.8 trillion dollars. Although this is obviously considerable, it represents an annual rate of only 2.2 per cent. That is somewhat lower than the growth forecasts for the world economy presented by *The Global 2000 Report* (Council on Environmental Quality, 1981: 44). It is also a slower growth rate than in any recent decade except the 1970s. The two main reasons are that IFs uses a Cobb–Douglas production function and that the global

population growth rates tend downward steadily in the reference run. Declining population growth rates gradually reduce the work-force growth rate. In addition, the reference run forecast for higher energy and food prices, especially the former, has an economic cost.

The economic gap between developed and lesser developed regions, as measured by ratios of GDP per capita, stays stable in the reference run. This is a continuation of the pattern of the last 25 years. In contrast, however, the gap in physical quality of life narrows, again as has been the case in the last two decades. Since the physical quality of life index is based on three measures (life expectancy, literacy, and infant mortality), all of which saturate, a narrowing of the gap is reasonable.

Global population in the reference case grows to 7.9 billion in 2025. This forecast is purposefully on the low side of UN estimates, because of the apparent tendency for many forecasts to adjust slowly to the increasingly rapid drops in LDC fertility. In the reference run global population growth falls from 1.7 per cent to 0.76 per cent annually over the 45-year period. Starvation deaths total 16 million over the period, overwhelmingly in Africa and Asia. This figure understates the real value for this run, because normal mortality statistics of LDCs (upon which the demographic model is based) do not report malnutrition-related deaths; people die of pneumonia or dysentery in statistics, even when the more fundamental cause is food shortage. Thus, some starvation is concealed in the 'normal' mortality statistics.

An additional reference run indicator in Table 3 is the global increase in atmospheric CO_2. By 1980 we had already increased those levels by 12 per cent (on an 1800s base); the forecast is for a 42 per cent increase by 2025. This variable actually affects nothing else structurally in the model, although climatologists worry about its real-world impact (Kellogg and Schware, 1982).

In the reference run, both the world food and energy prices increase considerably. The energy forecast appears high relative to many forecasts. Delays in switching to energy forms (coal, renewable, and nuclear) other than increasingly scarce oil and gas are the primary causes of the cost increases. A longer forecast with IFs often shows prices getting lower as investment in alternative energies promotes increased production.

GDP per capita increases steadily for all regions in the reference run. Table 3 illustrates this for four of the ten, specifically the United States and three LDC regions.

The results of the *liberal* scenario are dramatically different. Global product is 25 per cent higher in 2025 than in the reference case. Even more striking, the economic ratio between developed and less developed regions drops to 5.8. It drops to 9.6 by 2000, short of the value of 7 targeted by Leontief, but still remarkable. Similarly, the PQLI ratio falls to 1.11. Starvation is eliminated. Even energy and food prices prove slightly lower under liberal assumptions, in spite of a larger global economy, as a result of the increased investment availability. In fact food prices scarcely rise at all. The bad news, to the degree that there is any in this scenario, lies in relatively higher CO_2 levels.

One interesting aspect of the liberal scenario is that although GDPs per capita for all LDCs more than double 1980 levels, US GDP per capita is actually down relative to the reference run. This relative strength of LDCs is anticipated in some liberal writing (e.g., Friedman, 1962) as a result of policies more in line with a truly liberal world. In the case of IFs it can be traced primarily to the effects of lower food prices on the US agricultural sector.

The *radical* world achieves even higher total output, a full 52 per cent above the reference case, and the developed/LDC gap is down dramatically. Ironically,

however, the radical world narrows the gap less than does the liberal scenario, although the PQLI gap does close slightly faster. The explanation here can be found in the continued powerful growth of MDCs in the radical scenario. GDPs per capita of the four regions all increase nearly four-fold. In spite of relatively adverse terms of trade in the radical world, the MDCs do well because of the fairly dramatic decrease in military expenditures and because of increased investment rates. The Bariloche report (Herrera *et al.*, 1976) does not indicate whether it can produce similar results.

Anyone who is beginning to draw conclusions about the relative desirability of liberal and radical worlds from these scenarios, however, should go back and begin reading this article again. The inherent structural 'biases' of IFs, like those of any other model, strongly shape the results achieved here. That is exactly why this kind of exercise in exploring such model structures is so important. In this case IFs may well be exaggerating the economic benefits to be achieved by military expenditure reduction, perhaps because of author's bias. It may also underestimate the growth penalty for MDCs of adverse shifts in terms of trade.

The *neo-traditionalist* world moves into a collapse mode about the end of the century. As oil and gas resources rapidly disappear and as population growth overtakes the slow food production increases of the scenario, the economy begins actually to decline and starvation moves upward to staggering levels. Once the collapse begins it feeds on itself, investment rates decline and the labor force decline further feeds economic decline. Thus, collapse generates momentum as difficult to counteract, once it begins, as the momentum of growth.

One of the more interesting features of the neo-traditionalist scenario is the differential regional behavior. Only Eastern Europe and the Soviet Union actually end with higher levels of per capita GDP than those with which they begin, because of relatively autarkic economies and considerable coal resources. For similar reasons, the US performance is the best of the Western economies. None of the LDC regions do very well, but Latin America is especially hard hit. Its energy resources are limited and it is highly dependent on the outside world.

The *modernist* world proves considerably more comfortable than the reference run, although it may be a surprise that it does not look as good as either the liberal or radical worlds. The failure to match liberal or radical results occurs because the modernist scenario relaxes constraints on energy and agriculture which were never strongly binding in the reference run. In contrast, the liberal and radical worlds incorporate some significant 'policy' changes.

The combinations of *modernist* with either *radical* or *liberal* assumptions speak for themselves. In both cases more optimistic views emerge than with either liberal or radical assumptions alone.

The final and most *optimistic* scenario stands in stark contrast to the neo-traditionalist. It is hard to believe that the same model could produce them. Not only does global GDP reach 61 trillion (1980) dollars, but the developed/less developed gap drops to a ratio of 4.2. The physical quality of life gap nearly disappears. Energy prices return (after an interim rise) to near 1980 levels, and food prices in 2025 are little more than half those of 1980. Once again, the only issue for concern is the level of atmospheric CO_2, well on its way to doubling 1980 levels, which in all scenarios bar neo-traditionalist appears likely before 2050.

This section has not tried to make a quantitative assessment of the degree to which introducing changes into IFs actually reproduces results from earlier world models. Many obstacles to doing so exist, such as the fact that earlier models also produce a

mixture of scenarios, even if they vary less than those created with IFs. Moreover, indicators differ greatly among models, as do time horizons, and different base years for currency-measured values introduce further confusion. Most importantly, I never posited that IFs would duplicate numerical results, but rather that values relative to the reference case would differ in the expected directions, consistent with world views. That has been shown clearly.

Nevertheless, some numerical comparison is useful. For instance, several indicators from Leontief's Scenario X (the only one publically reported in detail) can be usefully compared with results from the IFs modernist-liberal scenario. Both models forecast from 1980 to 2000 (not shown for IFs in Table 3). Over the 20-year period, population in Leontief's model grows by 146 per cent, in IFs by 138 per cent. GDP growth is 259 per cent versus 190 per cent, respectively; food production grows 219 per cent versus 242 per cent. Leontief forecasts a drop in the developed-less developed GDP/capita ratio from 12 to 7.7, while IFs suggests a decline from 12.6 to 9.5. Although the numbers are not remarkably close, in each case the values produced by IFs in the modernist-liberal scenario have clearly moved in the direction of those forecast by Leontief, relative to the reference case.

Another interesting comparison is between the IFs modernist-radical scenario and the primary Bariloche scenario over the longer 1980–2020 period. Over the 40 years global population in Bariloche grows by 194 per cent, in IFs by 176 per cent; global GDP increases 313 per cent versus 411 per cent, respectively. Since regions are identified differently in the various models, the developed-less developed income ratio in Bariloche is 16.3 in 1980 versus 12.6 in IFs and 12 in Leontief. Over the 40 year period it drops 43 per cent in Bariloche and 47 per cent in the comparable IFs case. Again, the results are not strikingly close, but they are not bad. Actually the IFs scenario appears to have consistently 'overshot' somewhat the magnitude of changes needed to transform the reference case to the modernist-radical one.

Conclusions and Implications

The central argument of this article has been that instead of comparing and contrasting global modeling efforts on the basis of their forecasts, surface structural features such as submodels and regions, or even isolated equations, we should undertake a more detailed, yet simultaneously more integrated examination. Models differ dramatically in the images of the future they produce. Those images are shaped strongly by the world views of the modelers, sometimes made explicit, as in the case of Bariloche, but often unidentified. Those world views translate into model features and selective adaptation of theory in fairly understandable (if not always initially obvious) ways. Moreover, selection of parameters and data bases follows from the world views and the structural approaches taken.

An obvious conclusion is that such models should not be used as forecasting devices without a thorough understanding and communication of the highly complex if-statement which constitutes the model. Most of the models reviewed here present alternative scenarios, with the very strong implication that reality lies within the boundaries of that set. Yet the variation in each of those sets is fairly limited. This article has shown that *each set effectively constitutes a single scenario within the framework of a more general model.*

Realistically, it is difficult for most model or forecast users to understand the details of the model and therefore the if-statement being made by it. This article has

presented a framework for organizing an approach to such understanding and has applied it to several models and futures studies.

One conclusion to avoid is that models are of no value and not to be trusted or used. At a practical level, forecasting is part of decision-making. An explicit computer model with specific assumptions which can be communicated to others and reviewed or changed will often be superior to implicit and frequently ill-defined mental models.

At a scientific level, model building is theory building. In fact, the existing world models may be among the most explicit and easily studied statements of those descriptive and prescriptive theories which we have here called world views. Comparing and contrasting the models, and identifying the structural features and parameters which distinguish them, is thus an important step in the theory-building process, because it helps establish a research agenda for theory refinement. Throughout this article we have effectively identified key empirical relationships and important parameters which should be given more attention in future modeling and theory projects. Insofar as modeling is descriptive this is essential.

But we must be careful not to go too far in this direction of argument. Much of what differentiates world views is prescriptive. Many of the changes made to IFs in adapting it to emulate other models did not reflect differences in opinion about how the world does work, but rather over how it should work. These were most obvious in the radical scenario, but appeared throughout. Thus, some of the differences among models and forecasts will always exist, and we must distinguish these from the descriptive differences.

Social scientists, like the policy community, have expressed considerable interest in world models over the last few years. If that interest is to be rewarded by advances in theory, both modelers and those using models must make more serious efforts to understand, differentiate, and build upon the first generation of world models. That is what the work reported in this article attempts to do.

Appendix

Specific Parameter Changes in the Basic Scenarios

General
To establish the 25 year horizon, LASTDT was set to 2025; CYCLE to 5.

Liberal Scenario
To decouple economic and other submodels, AGON, ENON, KENF, SQUEEZ, BPDRF (all regions) and CLFN (all regions) were set to 0.0.

To increase investment rates, ISHIFT (all regions) was set to 0.01.

To increase labor force participation rates, LAPOPR for all Southern regions was increased by time series from 0.3 (first 3 years) to 0.5 in 2025.

Radical Scenario
To shift the terms of trade, TERMX was changed by time series from 0.0 to 0.2 in 2000 and held there.

To reduce military spending, GK was changed by time series in all regions from initial conditions (region specific) to 0.1 in 2025.

To change income distribution, Gini was changed by time series for all South regions from initial conditions (region-specific for the first three years) to 0.2 immediately.

To change crop loss asumptions, LOSS was changed by time series from 0.25 in Latin America to 0.05 in 2000, and from 0.35 (other Southern regions) to 0.15 in 2000.

To increase investment rates and labor force participation, the changes were identical to those of the liberal scenario.

To change labor force efficiency, RLEF was changed in Southern regions from 0.01 (first three years) to 0.02 thereafter.

Neo-Traditionalist Scenario

To change energy assumptions RESORF for oil/gas was set at 0.5 and for coal to 0.1; RDINR for coal was put at 1.

To change technological progress in agriculture, YLF was changed by time series for all regions from 1 to 0.6 in 2025.

To increase the productivity penalty for higher energy and other raw materials prices, KENF was set at -0.3; ELASDE at -0.01 for all regions; and RKEF for all regions was changed by time series from 0.01 (first three years) to 0.0 at 2025.

To introduce the feedback to labor from starvation, RLEF was changed by time series from 0.01 (first three years) to 0.0 at 2025.

To tighten investment credit, BPDRF was set for all regions to 0.25 for all time points.

Modernist Scenario

To eliminate energy system constraints, RESORF and RDINR for oil/gas were set at 10.0. In addition, the capital costs of renewable energy for all regions, represented by QE and RENEW, were changed by time series from 350 to 70 in 2025, and KENF was set to zero.

To accelerate agricultural technological progress, YLF for all regions was changed by time series from 1 to 1.7 in 2025.

To reduce crop losses, LOSS was changed as in the radical scenario.

To accelerate technological progress in the basic economy, RKEF for all regions was changed by time series from 0.01 (first three years) to 0.02 in 2025.

Investment increase was introduced as in the liberal scenario.

Notes

1. The models the Meadows' were involved with were preceded by the work of Forrester (e.g., 1971). Cole *et al.* (1973) provide a thorough review of these types of models.
2. Among other efforts to establish the validity of IFs, Liverman (1983) undertakes extensive sensitivity analysis and historic validation, especially of the agricultural submodel.
3. Appendix contains specific parameter changes for replication purposes.

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