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William D. Nordhaus

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World Modelling from the Bottom Up*

William D. Nordhaus

Although opinions about world models vary from extreme enthusiasm to unbridled outrage, there can be no doubt about the success on one front: world models are the growth industry of the social sciences today. Three years ago the Club of Rome could have been the euphemism for the local wine-testing group. Today, it is hosting a pilgrimage of world scientists in Berlin to view the latest models in the haute couture of world thought.

A preview of one of these models was given during October 1974, in a three day meeting in Baden, Austria, hosted by the International Institute for Applied Systems Analysis (IIASA). The work presented there was a project prepared by the Fundación Bariloche, a multi-disciplinary group of scholars from Argentina. The most fascinating aspect of the Bariloche model is that it is a model about the world economy built from the bottom of the economic ladder looking up, rather than an elitist model built from the pinnacles of the Cambridges--Massachusetts or England--looking down (or into the future) at world problems. This perspective gives the model a ring of authenticity. Whereas World Dynamics and The Limits to Growth struck many as basically computer games,[1] the Bariloche model has finally come to grips with the concrete problems of mankind. It is interesting that in so doing they have combined a radical political philosophy with a traditional set of techniques.

In what follows I will try to lay out the basic setting of the Bariloche model, with close attention to the problems of techniques and methodology. If I seem to harp on the shortcomings, it is only because I think that the project's strong points are vitiated by inattention to some important details. It is an incomplete model, one that cannot at present be taken terribly seriously as a normative or descriptive model of the world economy; but nevertheless it represents a significant improvement over the Limits to Growth models which have been used heretofore.

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*The work discussed here was presented by the Fundación Bariloche in a series of forthcoming papers to be published by IIASA.

[1]My objections to the World Dynamics and Limits to Growth type of models are contained in "World Dynamics: Measurement without Data," The Economic Journal, 83, 332 (December 1973), 1156-1183.

The Underlying Structure

The structure of the model can be described in terms of five aspects: the philosophy, the techniques, the objective function, the constraints, and the results. Before getting into the details of the model, it is best to note one important feature of the model which distinguishes it from earlier models: the Bariloche model is an "optimizing" model, sometimes also called a normative model. Rather than attempting to project future trends unconditionally, the Bariloche model sets out an objective function for the different regions of the world and maximizes this. This procedure has certain advantages and defects, to which we will return, but it is a major break with earlier world models.

The Philosophy

The authors emphasize the need for an explicit philosophical and ethical basis for their model. For the most part, optimizing models have been quite pedestrian in formulating objective functions; thus we customarily find minimizing cost or maximizing GNP as objectives in empirical growth models. The Bariloche model is most imaginative in this respect, for they have formulated a most unusual objective function and have rationalized this on radical philosophical grounds.

The documents presented by the Bariloche group teem with ideology and fulmination against various ills. Much of it is controversial; for the most part the philosophy is actually irrelevant to the underlying objective function of the model. Nevertheless it is useful to lay out the normative aspects of the model. According to the authors, the model has been built around basic assumptions, of which the two following are the most important.

(1) The final goal of the model is an egalitarian world society. Whereas earlier models have stressed the possible catastrophe faced by mankind in the future, the Bariloche model draws attention to the actual catastrophe faced by the majority of mankind today.

The most important manifestation of this egalitarianism is that the report posits the basic principle that each human being has the right to the satisfaction of a set of basic needs; these are quantified in the model as a minimum standard of food, housing, health, and education.

(2) The society should tend to move toward a "non-consumist" society. It is not clear what is meant by the term "consumist," but it sometimes refers to the "fetishism" of increasing consumption, as an end in itself, and sometimes to the consumption of material (or resource-intensive) goods.

With these assumptions, the group plunges into the middle of an extensive debate about the goals of economic growth. Speaking personally, I find the first principle quite convincing. It states that the provision of the basic needs, defined quite concretely, of the majority of mankind living today as well as in the future should be at the very top of our list of priorities. Historically speaking, it can be argued that societies have generally done too much for future generations and too little for the poorer members of current generations. And until we are convinced that meeting the basic needs of today's poor countries will lead to general impoverishment of the future, we should be suspicious of counsels which favor the generalized future at the expense of today's poor.

On the other hand, I think that the Bariloche group's hostility to the "consumist" society is misplaced. They have perhaps confused the doctrine of consumer sovereignty, the philosophical basis of much Western economic thinking, with the crasser and generally ill-conceived desire to maximize GNP. Modern economic thinking holds that GNP, especially GNP as conventionally measured, is not the proper index of economic welfare; and certainly it is not the same as the quality of life. Rather, modern economic thinking rests on the proposition that the preferences of the citizens--somehow weighed and somehow determined--are taken as the ultimate goals of economic society. Of course, there are the familiar and insoluble problems associated with the issue of innateness or adaptability of tastes, as well as the role of externalities, information, and advertising; but these should not cloud the basic proposition that it is the consumer's own preferences--not the BBC's, or Galbraith's, or the Bariloche group's--which are the ultimate touchstones of value in a democratic society. The Bariloche group argues that it would be desirable to have a shift in emphasis to "enlarge cultural options--increasing leisure time--instead of increasing the consumption of material goods." The only difference between the thinking of the Bariloche group and modern Western economic thought is that the former thinks the shift is definitely desirable, while the latter would think it desirable only if consumers demonstrated (through the appropriate market or non-market forces) that they would prefer such a shift.

Aside from a misreading of current thinking of the proper direction of economic growth, there are two further strands in the desire for the non-consumist society. First, the Bariloche report stresses that the developed nations consume the lion's share of the world's food and natural resources, and that reduced growth of the developed world would reduce the pressure on these goods. This is a very complicated question, and the truth of the proposition is not at all clear. We return to this in the section on results. More basic to

the hostility to the consumist society, however, is the strand of thinking which questions the role of competition and market-domination in society. This also is a very sticky issue; they are undoubtedly right that the competitive game that is played in industrialized societies has immense social costs which have to be weighed against the immense benefits. I have never seen this problem persuasively answered, but I suspect that it is difficult to prove that the competitive structure is clearly an inferior form of organization.

In summary, they should concentrate their fire on the issue of meeting the basic needs of the poor rather than on denigrating the value of consumption in developed countries. The important point is not that the automobile or the airplane is inherently evil, but that the social importance of these pales beside the basic needs for food, shelter, and other necessities.

Techniques

Before we get on to the interesting details of the model, there is some methodological underbrush to be cleared away. First, let us consider the use of statistical techniques. The Bariloche model differs from the earliest Limits to Growth models in that it makes significant use of statistical procedures for determining the parameters of the models. On the other hand, the presentation of the statistical material is considerably below the accustomed standards in scientific work: only correlation coefficients are presented, without any indication of the standard errors of coefficients, or other useful summary statistics. This apparently is not an oversight, for at the conference one of the Bariloche group argued against the use of statistical techniques, but there is apparently no reference to this aversion in the written documentation. It should be noted that even if the group prefers to ignore the statistical tests, it is useful for others to present them, since these are the standards in many sciences. Moreover, it was perhaps a slip, but the group did appear to point to the general goodness of fit of the relations in attempting to demonstrate their validity.

Second, the major difficulty with using the Bariloche model as a predictive model is that the authors have attempted to be "conservative" or "pessimistic" about what is technologically possible. Thus in the economic model, they have assumed that there is no technological change, thinking that this would be a kind of worst case, or a worst plausible case. On the other hand, they appear to be "optimistic" in other parts, such as the energy and natural resources sector.

The notion of "conservatism" is a most treacherous one, and one which has been used in an unscientific way in this as well as other global models. What does it mean to say

a projection is conservative? Presumably it means that there is only a "small" subjective probability that the outcome can be "worse" than the path under consideration. In what way "worse," and how "small"?

I do not see how these questions can be answered intelligibly outside of a statistical (or a subjective-probability) framework. I have seen no attempt in global modelling to apply statistical decision making to the problem of model validation and sensitivity analysis, but the statistical approach is clear and relatively straightforward. Since the subject is so important, I will spell it out in some detail.

The Bariloche group has the following problem: maximize a function $U(\underline{x})$ subject to constraints $f^i(\underline{x},\underline{y}) = 0, i = 1,\ldots,m$, where $\underline{x}$ and $\underline{y}$ are vectors of variables. We are generally interested not only in the validity of the structure (e.g. accuracy of the functions), but also, and especially in world models, in the accuracy of the predictions. Thus in the Limits to Growth model many of the criticisms were directed both at the unrealism of the assumptions and the unreliability of the conclusions.

In principle, we can formulate the problem of validation of the simulation model as follows. Let us simplify the problem such that it is linear in a set of parameters $\underline{a}$ and $\underline{b}$, where $(\underline{a},\underline{b}) = (a_1,\ldots,a_n,b_1,\ldots,b_{nm})$:

$$\max_{\{x\}} \sum_{i=1}^{n} a_i x_i$$

subject to

$$\sum_{i=1}^{n} b_{ij} x_i = 0, \quad j = 1,\ldots,m \quad .$$

Through a combination of prior restrictions and empirical analysis, we can place a joint distribution on the $\underline{a}$ and $\underline{b}$, e.g. $g(\underline{a},\underline{b})$. Through the maximization we get then a time path of the state variables, $\underline{x}$, which is a function of the coefficients $\underline{a}$ and $\underline{b}$, e.g. $x(t) = \Phi(\underline{a},\underline{b})$. Finally the distribution of $\underline{a}$ and $\underline{b}$ will lead to a distribution of the outcomes $h(x)$ where $h(x) = \{g(\underline{a},\underline{b}) | \Phi(\underline{a},\underline{b}) = \underline{x}\}$. If Φ is a one-to-one transformation, we can write $h(\underline{x})$ as $h(\underline{x}) = g\{\Phi(\underline{a},\underline{b})\}J$, where J is the Jacobian of the transformation from $(\underline{x})$ into $(\underline{a},\underline{b})$. (This formula applies only in a very restricted set of cases.) An illustration is shown in Figure 1. This, of course, is very similar to the problem of prediction intervals which come out of the simplest linear regression.

There is nothing revolutionary about this suggestion; rather it is simply the result of applying the normal operating rules of scientific enquiry to the arena of global modelling. If it were carried out, in even a simplified way, it would allow the predictions of the models to be subject to the same kind of review as the output of other scientific research. Up to now the evaluation of the predictions of global modelling has been extremely difficult. An attempt to validate them has been pretty much hit or miss, relying on the intuition of the investigator to identify the important variables. The procedure of statistical validation would put validation on a much more objective basis.

A more important consideration is that a statistical procedure would make the notion of conservatism or pessimism a meaningful and quantifiable notion. The principle of pessimism (or planning for rainy days) is indeed important; it signifies that if we are unpleasantly surprised by the outcome of population growth or technology we should not find we have backed ourselves into a corner. But the decisions can be meaningful only if we know how remote the possibilities of the pessimistic event are. How likely is it that we will experience no technological change over the next fifty years?

On a practical level, the requirement for statistical validation would mean that it would be almost impossible to test the grandiose world models used up to now. There are hundreds or thousands of parameters, and to estimate the "standard error" of the forecasts would be prohibitively expensive (even if the authors believed in such tests). But this "impossibility conjecture" makes quite explicit something which has only been intuitively obvious about large models: they are simply too big to evaluate. Until a group can present at least a partial description of the probability distribution of the output variables, similar to that in Figure 1, it has not completed its work of examining the properties of its model.

In the Bariloche model I conjecture that these tests would lead to major discontinuities in the outcome space, that is, that small changes in some parameters would lead to drastically different conclusions (for the reasoning, see below).

Third, there is a minor point which was brought up in the conference about the choice of model selection. It was stated that the Limits to Growth model is a poor model because the outcomes, or predictions, are very unstable with respect to the model parameters. While it is nice from a mathematical point of view to have a stable model, there is nothing in human affairs which dictates this condition. Indeed, the Bariloche model is a member of what might be

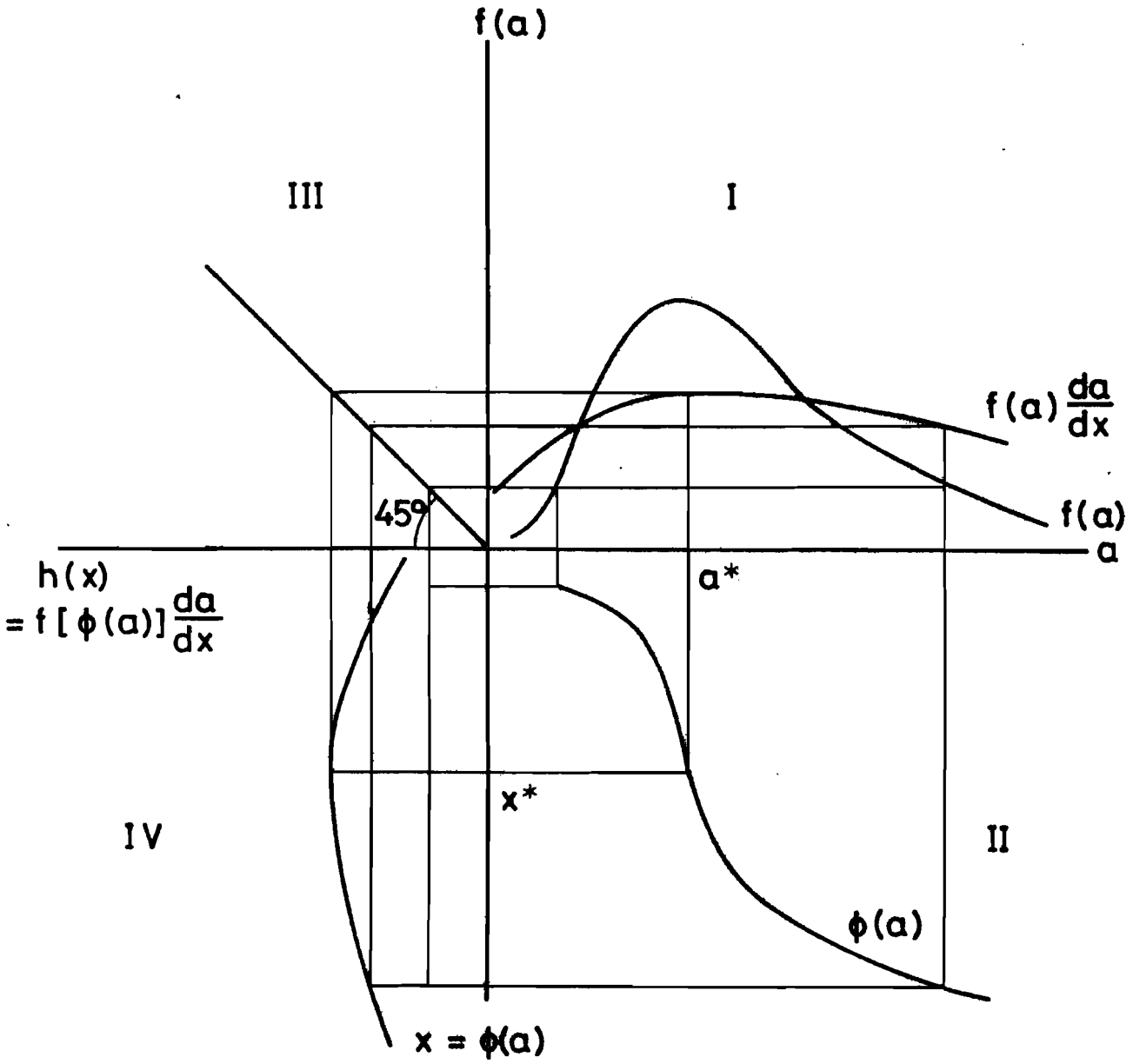

Figure 1. This figure shows the relation between the distribution function of the unknown parameter a and the output variable x. Quadrant I shows the distribution function of the unknown parameter a, f(a), and the product of the density function and the Jacobian of the transformation, f(a)(da/dx). Quadrant II shows how the output function is related to the unknown parameter. Quadrant III is a reflective line, reflecting f(a) (da/dx) into Quadrant IV. Quadrant IV shows the resulting distribution of the output parameter. In this example (a*,x*) is the maximum likelihood value of the unknown parameter and the output variable.

Note that the conditions under which the distribution of the prediction path $f[\phi(a)](da/dx)$ is continuous with respect to the parameter, a, are extremely stringent.

called Malthus-Nelson models[2] which show multiple equilibria, and some of the sensitivity analysis, as well as the runs themselves, suggest that the model has multiple equilibria.

The Objective Function and Optimization

Perhaps the most original and interesting aspects of the Bariloche model are the details of the objective function and the optimization. The objective function is unique in two respects: first, it is designed so that its basic variables are quantifiable in natural units rather than in value units (or utilities). Second, it is an objective function which "satiates" at relatively low levels of performance.

More specifically, the basic objective is to

$$\max (1 + \text{qlife})\ \text{le} \qquad (1)$$

subject to numerous constraints, where

and

- le = life expectancy at birth
- q life =
  - 0, when the "basic needs" have not been satisfied;
  - share of consumption (excluding "basic needs") in GNP (including "basic needs"), when basic needs have been satisfied.

As far as the basic needs are concerned, these are the four categories mentioned above--food, education, housing, and health--and the targets for these are set in quantitative terms:

(i) Calory intake per capita must exceed 3000 per day, and in addition have a reserve for "rainy" days.
(ii) At least 98% of the relevant population must be enrolled in school, from age six, for twelve years.
(iii) Each family must be provided with a "house" of minimum quality; this is basically fifty square meters plus certain sanitary and other equipment.
(iv) Health enters directly through the objective function.

The model then maximizes the value of the objective function subject to the constraints. The authors suggest that in principle they would like to define the optimal path as one which attains the required levels of the "basic needs" in minimum time (and, presumably, stays there). Neither the

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[2]The Nelson analysis of the Malthusian model appears as in Richard R.Nelson, "A Theory of the Low-Level Equilibria Trap in Underdeveloped Economies," American Economic Review, 46,4 (December 1956), pp.894-908.

techniques nor the objective function seem designed to perform that task well. The actual procedure is to maximize the objective function every year, i.e. myopically, without taking into account the effect of current decisions upon future levels of the "basic needs."

It is not clear whether the authors believe that the procedure actually used is equivalent to the technique of minimizing the time to satisfy the basic needs and to stay there. A simple example will show that in general it is not. Consider a very simply economy in which there is a fixed pool of resources $R > T$, and where T is the lifetime of the society, life expectancy at birth is a concave function of consumption of the resource, and where the basic needs require one unit per period. A perfectly myopic policy, one which maximizes life expectancy at birth, will have a "potlatch policy." All R units will be consumed in the first period, after which society collapses. (It is interesting to note that this policy looks not dissimilar to the outcomes for Africa and Asia in the model runs without economic aid.) In this example, there are several policies for minimizing time to meet basic needs and to stay there since it can be done immediately; any sensible policy in this context would surely not look like the myopic policy.

The surprise, at first blush, is that the outcomes of the model runs do not look ridiculous (as does the myopic policy just described). It is here that the constraints play a most important role. It appears that the authors have constructed the constraints so that it is not possible to have a potlatch policy. The most important variable controlling the distribution of consumption over time is the rate of investment, but the runs are constrained within the ridiculously narrow band of 21% to 25% of GNP during the phase before the basic needs are satisfied. This constraint is puzzling, for it surely has no serious ethical or economical rationale, until it is understood that the myopic policy would drive the investment rate in a myopic direction. Other constraints can be interpreted in a similar manner.

As a result, it can be argued that the results of the optimization cannot at this point be taken seriously as prescriptions for development. It is imperative that the authors quickly attack the problem of a more reasonable objective function. I suspect, however, that this will be a most difficult problem because of the nature of the constraint set. First, if they continue to use the objective function described in equation (1), they will have difficulties because it has a kink at that point where the basic needs are satisfied. More significantly, I think that the underlying constraint set is not a convex set because of the way in which consumption has a restraining effect on population growth.

A second question which is raised by the model is the universality of the particular objective function they use. The introduction of life expectancy as a primary variable is explained as follows:

> In the model, life expectancy at birth was selected as the key variable to be maximized, due to the fact that besides being affected by all the endogenous socioeconomic variables of the model, it is a much better indicator of the real conditions of life in a society, than a purely economic index as the gross product. Moreover, it reflects quite clearly an unequal distribution in a country or region when compared with the GNP per capita.

There are two strands in this argument: first that the life expectancy is affected by all the endogenous variables, and second that it is a superior indicator. The first reason is correct, but it is a very dangerous principle to use in an optimizing model. To see the danger, suppose that the true objective function is U (le, qlife) = 4/5 log (le) + 1/5 log (qlife), where U is a preference function, and le and qlife are defined above, Further, let us assume that in societies where development proceeds more or less without control, the two variables (le and qlife) move very closely together. Assume that the model has correctly described the constraint set between them as $(le^2 + qlife^2)^{\frac{1}{2}} = k$, where k is a function of time, labor and capital. The constraints and objective function are shown in Figure 2, with the "optimal" solution, e.g. the preference maximizing solution, given at (le*, qlife*).

Let us suppose that, within an optimizing framework, we follow the reasoning cited above and use life expectancy as a proxy variable for the true objective function. Clearly, we would end up at point B in Figure 2, with a long but miserable life. On the other hand, if we take the stereotype of the economic criterion function, maximizing the quality of life, we end up at point E with a short but affluent life. This problem is especially acute in optimizing models, where the optimization focuses with singleminded obsession on objectives with high payoffs and ignores completely those with low payoffs. (The problem is compounded if the feasible set is only imperfectly known. The optimal plan will be even more distorted if some of the behavior relations are measured with great error and no account is taken of this in the optimization).

In light of the cautions outlined above, the question is whether the Bariloche group has used a distorted objective function. This is obviously a matter of society's preferences, but for my taste they have overestimated the value of pure

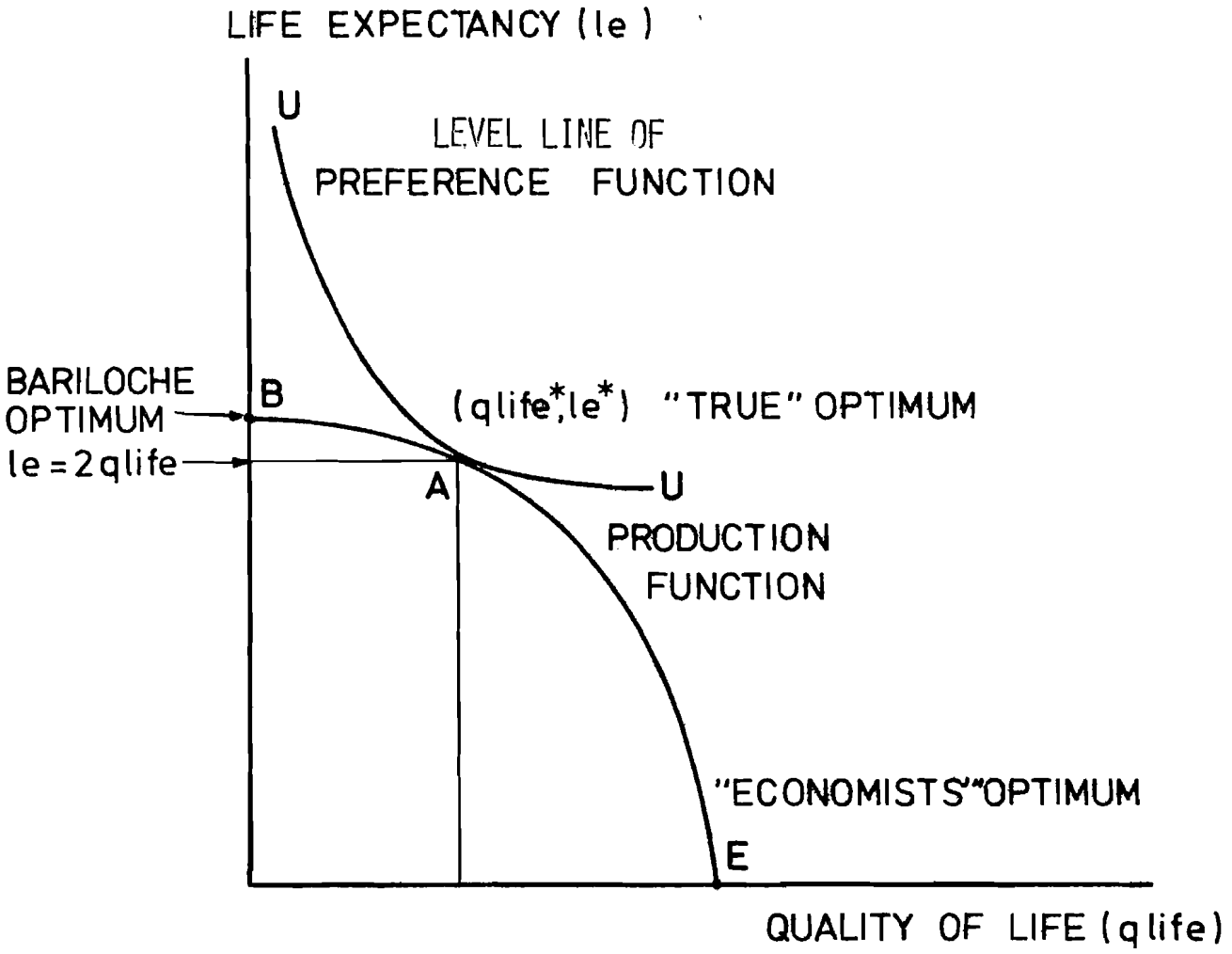

Figure 2. The figure shows the danger of using proxy variables in optimization. The true preference function is UU, while the constraint is BAE. A true optimum will lie at A, while "single-minded" or proxy optima will lie at B for the Bariloche optimum and at E for the "economists'" optimum.

longevity and underestimated the value of the quality of that longevity. It is much more difficult to construct an objective function with all the aspects of a desirable life style; but if we are to avoid the distortion of looking at single indices (whether GNP or life expectancy) we must do it right. The use of GNP (or more properly, a generalized consumption measure) in optimizing programs is open to many objectives, but the usual objections are that the usual accounting system is too narrow, not that it is too broad. If we are to correct for the deficiencies of the GNP, we must include many items which are left out (leisure, culture, environmental goods, etc.). The Bariloche group has gone in the opposite direction, leaving out important variables which usually are thought to enter into economic welfare. For all its shortcomings, I think that some generalized consumption measure (including perhaps physical constraints of the kind used by the Bariloche group and correcting for the length of life) should be used instead of the simpler objective function of life expectancy.

If the Bariloche group is to continue to use the objective now in the model, there is one further problem which should be noted. Turning back to the objective function, note that until the basic needs are met the objective function is simply life expectancy. It is much more in accord with the reasoning of the group to give a very high weight to attainment of the objective of meeting the basic needs. The problem is illustrated in Figure 3. Forgetting about housing and education (assuming that these are costless), the objective function is simply (1 + 0)le, or le until the food constraint is satisfied, and then equal to $(1 + \frac{\text{Consumption}}{\text{G.N.P.}})$le after that point. This seems a pretty paltry reward for attaining the objective of meeting the basic needs.

A better way of representing the importance of meeting the basic needs would be to have a stronger reward for attaining the basic needs. Perhaps have no reward until basic needs are satisfied (such as having the objective function be 0 if they are not all met).

A related problem is the use of the share of consumption in GNP as the index of the quality of life. I cannot imagine how this could have arisen. Perhaps it comes from the idea of a relative income notion, that once the basic needs are satisfied, further consumption is like drugs in simply building up craving for further goods (is this the definition of a consumist society?). Perhaps in some ultimate way humans do satiate at some level of consumption around that now experienced in the United States or Western Europe; if this is the idea, it should be introduced explicitly rather than through the share of consumption.

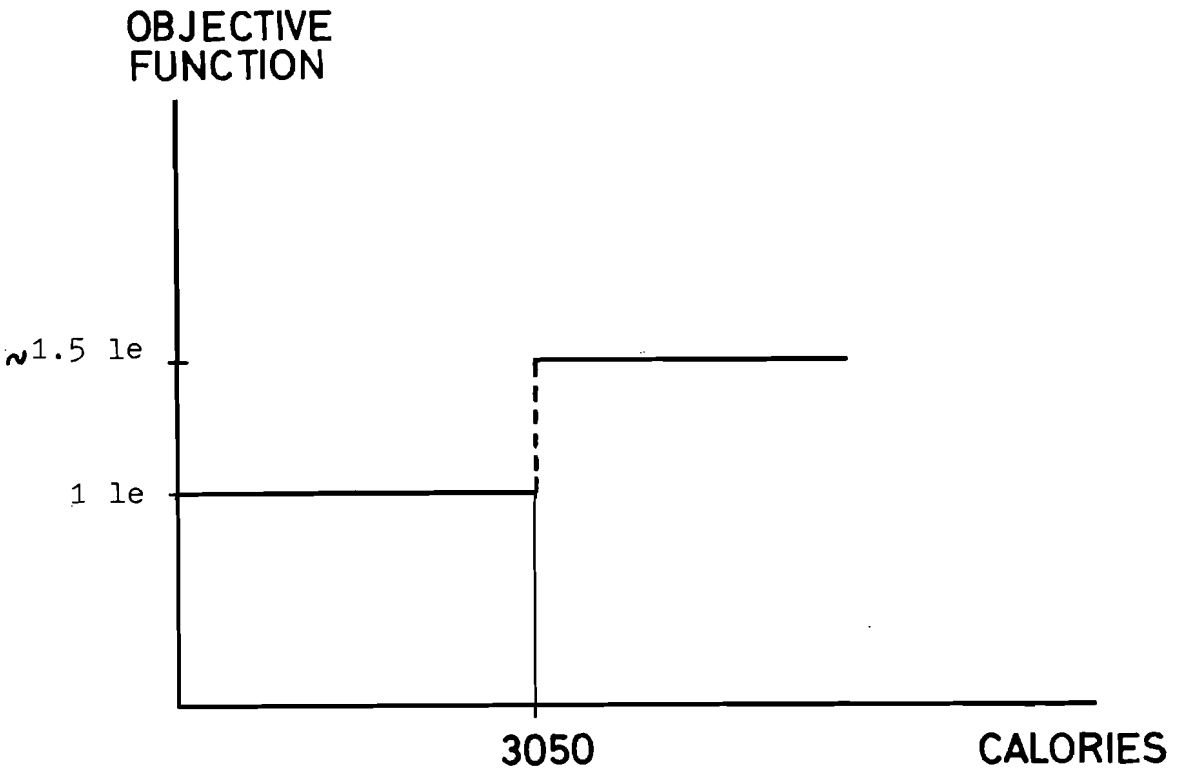

Figure 3. This figure shows how the objective function varies with the level of the basic needs. Note that there is no penalty when the level of calories is less than the minimum, whereas a jump takes place as soon as the basic level is reached.

Within most systems there are "policy variables" which can be to some degree affected or determined by the agents, whether these be economic, political, or social. These policy variables include the rate of investment, the allocation of investment and labor between the different sectors, the level of taxation or subsidy of different sectors, the extent of family planning, and so forth. What is the proper way of treating these variables in world models? Some earlier models (World Dynamics and The Limits to Growth) were accused of simply projecting the trends rather than providing for some adaptive response in the policy variables; other models, particularly economic models, have been accused of assuming too optimistic a level of responsiveness of markets and policies to changes in economic conditions.

In general there are two kinds of approaches to the treatment of policy variables. The first (which would be the technique of modern political science) would be to treat the decision makers as behavioral, and to derive the corresponding behavioral relations. Thus, one would try to determine the actions which were profit-maximizing on the part of firms, preference-maximizing on the part of consumers, vote-maximizing on the part of competing politicians, and work-minimizing on the part of bureaucrats.

If the behavioral regularities were difficult to estimate one could substitute the preference function of the agents into the problem and maximize the agents' objective function. (Interestingly, one of the justifications of the myopic objective function used by the Bariloche group was that governments tend to be myopic.) This approach is really a descriptive one, using optimization as a technique, since it uses the decision maker's rather than a more general objective function. A more traditional optimization would be to use a general objective function, rather than that of a single interest group. This has been the approach of the literature on optimal economic growth, following the tradition going back at least to Jeremy Bentham. This can also be described as a way of tracing out the set of feasible strategies for an economy.

It is not clear which of these approaches the Bariloche model has followed, although the language is basically that of the second, and truly optimizing approach. It should be stressed that if the goal is true optimization it is imperative that a global rather than a myopic objective function be used.

The Constraints

The constraints on the world economy define the boundaries within which any optimization must lie. Roughly speaking, there are three sets of constraints: economic, demographic, and "realistic" constraints. The economic constraints are sets of conditions which limit the production of the various sectors of the economy, where the limits are the amount of primary factors--capital, land, and labor--which are available. These are taken to be the well-known Cobb-Douglas production functions:

$$Q_i = K_i^{a_i} (L_i A_i)^{1-a_i} \quad , \quad i = 1,\ldots,5 \quad ,$$

where A_i is implicitly the productivity of labor and Q, L, and K are output, labor, and capital, respectively. The five sectors are food, housing services, eduction, other consumption, and capital goods. The usual constraints on total labor and capital, as well as capital accumulation, appear to be observed. I could find no reference to the allocation of land, but it appears that land is allocated between sectors according to a linear programming subroutine. It would seem more natural to include land in the basic production functions.

There are many questions which arise in the economic model, but the most important are the following:

First, it is explicitly assumed that there is no further technological change in any sector or any country. This is an extreme assumption, explained by the desire to be "pessimistic" in drawing conclusions. As noted above, it would be far superior to treat the problem from a decision-theoretic point of view so that the degree of conservatism could be judged. As we will indicate later, this is a crucial question in judging the verisimilitude of the results.

The economic blocks in the model are completely separate in their economic relations. There is no room for trade, imperialism, exploitation, cartels, terms of trade or any of the other interesting features of international economic relations. In fact, the only link between the blocks is capital flows (or economic aid) which is imposed in the second major run of the world model.

Further there are no resource, energy, and pollution constraints in the economic model. In earlier global models, especially the Limits to Growth, these three factors formed important constraints on the economic growth of the world economy. The Bariloche model, on the other hand, investigates the problems posed by these three sectors and concludes that it is more a problem of cost than of absolute limits. Thus

by going to lower grade mineral resources the necessary minerals can be found; by going to new technologies the requisite energy resources can be produced; and by paying attention to environmental constraints clean, if slightly more expensive, technologies can be used. The reasoning was on the whole convincing. On the other hand, I detected an optimism about the advent of new technologies that does not square either with the professed pessimism of the report or with some nasty details of the new technologies; in particular, I think they may have underestimated some of the environmental problems and other costs of new technologies.

The demographic part of the model is more difficult to evaluate. The most important difference from earlier world models is that the Bariloche group has used estimated rather than hypothetical equations; thus the parameters of the birth, mortality, and other functions are drawn from cross-sectional data on more than 100 countries. For this reason they observe the phenomenon known as the demographic transition--that the rate of growth of population declines after countries have reached a certain level of economic development. (Ignoring this phenomenon was the essential reason that the earlier models of Forrester and Meadows et al. found such pessimistic conclusions.)

As far as the exact equations are concerned, they seem somewhat dubious. It is very difficult to assess the extent to which the parameters are well determined without the standard errors of the coefficients. Moreover, the demographic model seems to contain inconsistencies; the birth rate and the mortality rate are separately determined from the fraction of the population between 0 and 9, 10 and 14, and so forth. Thus one variable (calorie consumption) affects the birth rate and the mortality rate without affecting life expectancy: how is this possible? Similarly, the distribution of the population is determined by a variable which does not affect the birth or death rates or the life expectancy (e.g. T.C. [an unidentified variable]). Perhaps it was too complex to build up a correct life table, but the inconsistency is somewhat disturbing.

In addition to the constraints already discussed, there are a number of what appear to me to be essentially nuisance constraints. These fall into two categories: flow constraints and level constraints.

The flow constraints are those which keep the system from moving from one position to another too rapidly. They make good sense, in that there is considerable inertia in economic and social systems, but they are essentially arbitrary. These constraints, for example, mean that prices cannot change too rapidly, that enrollment cannot grow faster than 10% annually, and so forth. In addition, there is one flow constraint which

insists that the basic needs (calories, housing, and enrollment) cannot decline from one year to the next. This is stated as an objective, but it is hard to know whether it is very costly; I could conceive of situations where a temporary decline in consumption could be tolerable.

In addition there are level constraints. The most important, and to me the most objectionable, is the straitjacket put on investment. In the period before the basic needs have been met the investment rate is constrained to lie between 21% and 25% of GNP. I can conceive of no general value system which would impose this rule. It essentially fixes the investment rate. One interpretation, in light of an earlier interpretation, is that this constraint is imposed to prevent the system from consuming everything immediately--a path which would probably be dictated by the myopic objective function.

A similar constraint is that general consumption (sector 4) must never be below 42% of GNP. This seems a rather strange constraint for a model which is critical of the "consumist" developed economies. Again, it is probable that this constraint is imposed by the objective function: recall that the objective function in the early stages rewards only life expectancy. On the other hand, general consumption (sector 4) does not help life expectancy. A myopic optimization would presumably drive consumption to zero, along with capital investment, so it would be necessary to impose the external constraint on the share of consumption.

In both these cases, the myopic objective function has produced a distortion in the growth path and thereby led to the imposition of dubious constraints.

The Results

A set of results of the Bariloche model was presented at the conference at Baden, and these will be discussed very briefly here given that they are preliminary.

The simulations were run for four blocks, (1) the developed countries, (2) Latin America, (3) Africa, and (4) Asia. In run I, each block evolved completely on its own, with no capital flows or economic aid from outside blocks. In this run blocks 1 and 2 continued to grow and reached a kind of satiation level, while groups 3 and 4 had an initial burst of growth, then ran out of gas and declined. The reasons that Africa and Asia did not "make it" are not spelled out, but I would guess that they did not make it past the demographic transition; thus they had initial increases in consumption, enrollment, calories, etc., but these were insufficient to reduce the rate of growth of population. Thus population continued to grow very rapidly, around 2.5% annually, leading to exhaustion of available land and finally deterioration of the living standards. Latin America, on the other hand, made it over the demographic transition and the rate of popu-

lation growth declined steadily from around 2.5% in the early 1970's to 0.5% by 2020.

A second run was presented in which the developed economies gave aid to Africa and Asia, where the aid amounted to 2% of the GNP of the developed countries. In this case, Africa and Asia made it over the demographic transition and their development looked very much like that of Latin America.

The report concludes with the statement: "In conclusion the run shows that the developed countries, by allocating to economic aid half of the funds they are now devoting to the arms race, can decisively contribute to rescue more than a half of mankind from its present misery."

In many ways the runs are the most fascinating part of the report; they show in a very dramatic way the way that a population behaving according to the theory of the demographic transition can lead to very different paths of economic development according to the initial conditions and the economic policy. At the same time, however, it seems to me that the runs cannot be taken very seriously as descriptions of the options facing mankind.

First, because of the conservative nature of some of the assumptions, the runs may underestimate the potential for growth of the different countries. Perhaps the most important of these conservative assumptions is that there will be no further technological change in the developing countries. When confronted with this criticism, the Bariloche group offered to make a run in which technological change occurred. The particular parameters used were that all sectors would have the same rate of productivity growth experienced by the United States from 1889 to 1953.[3] (Is this optimistic?)

The results showed a completely different pattern from those presented in the written report; in particular, all blocks grew quite rapidly and attained the minimum level of the basic needs within a very short period of time, even without economic aid.

There are of course very difficult questions involved in the projection of technological change over time. At the very least, this alternative run shows that the forecast path is quite unstable with respect to the parameters for technological change; at the most, these results show that the Bariloche model is grossly pessimistic about the future in poor countries when even myopically optimal policies are followed.

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[3]For the basis of the estimates, see J.W. Kendrick, Productivity Trends in the United States, Princeton, N.J., Princeton University Press, 1960, pp.136-137.

The second reason for questioning the results is the myopic objective function followed. It seems very likely that if a global objective function is used, such as minimizing the time to meet the minimum basic needs and to stay there, such a path could be found. This of course remains conjecture at this stage and will be tested in the future when the Bariloche group presents further results.

One other set of results, or perhaps attitudes, of the Bariloche model should be weighed. This is the view of the group about the role of economic growth in the developed countries on the future of the underdeveloped countries. The group argues that the continued growth of the developed countries is undesirable, as noted above. Yet in the model there are no links, aside from aid, between the two groups. It seems out of place to argue on the one hand that there are no physical limits to growth, and to hold on the other hand that rapid growth in the developed countries is a drag on the growth of the underdeveloped countries. It is clear, for example, in the model with economic aid that rapid growth in the developed countries would lead to more rapid development of other countries, since the aid is a fixed fraction of the GNP of the developed countries. Some have argued, in addition, that the fraction of GNP contributed in economic aid is likely to be higher in a growing economy than in a stagnant economy, but this is more difficult to demonstrate. In any case, the economic argument against growth in the developed countries is very weak. In a more realistic model with trade the general presumption would be that more rapid growth in developed economies would stimulate the developing economies through the effects on the terms of trade and the demand for exports, in addition to any effect on capital flows or capital transfers.

The chief argument against growth in developed countries is probably the "demonstration effect"--that growth in developed countries stimulates the wasteful diversion of surplus of developing countries to luxury consumption. In addition, there is the simple but powerful value judgment that great discrepancies in the distribution of consumption are ugly. But these costs of growth in the developed countries must be weighed against the presumptive economic evidence that growth in the developed countries would be helpful for economic development of less developed countries.