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MEMORANDUM FOR THE RECORD

SUBJECT: Conferences with Dennis L. Meadows, Pugh-Roberts, and Jay W. Forrester regarding Systems Dynamics

Dennis L. Meadows

Associate Professor of Business and Engineering, Thayer School of Engineering, Dartmouth College, Hanover, N.H. 03755 [redacted] STAT

STAT [redacted] and I met Professor Meadows at his office at Murdough Center at Dartmouth about noon on 31 July 1973, went to lunch with him, and then continued our conference at his office. He was very cooperative and forthcoming throughout the 2 1/2 hour period -- a dynamic and enthusiastic individual, obviously highly motivated toward achievement, practical and realistic.

Although he is not very familiar with intelligence he believes the systems dynamics methodology has much to offer since it is uniquely suited to analysis when precise relationship, and accurate, objective measurements are not available or can't be determined. He discussed four kinds of analyses: philosophical - in which there is little restraint on the framework; communications - in which the objective is to describe various notions or relationships; projective - in which greater structure is provided and more factual or assumed data is employed; and predictive - typified by physical and engineering equations in which the relationships are known with great precision and the dynamic or time related behavior of a system can be confidently predicted. Systems dynamics is effective in the communication/projective areas -- it does provide structure and an insight into the dynamic characteristics of systems which is difficult or impossible to achieve otherwise.

Based on his experience as a teacher, and as an organizer and lecturer of seminars in the systems dynamics methodology, he felt that the three week introductory course in systems dynamics which we are considering was about right for our purposes, i.e. providing sufficient

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working knowledge to analysts and others with little or no mathematical or computer background to make an intelligent assessment of the potential usefulness of applying the systems dynamics methodology to their problems. Meadows recommended that several changes in content and sequence be considered to make the course more effective. He believes it is very important to quickly immerse the student in real problems instead of trying to complete the development of the theory before getting into applications.

I purchased a pre-publication copy of The Dynamics of Growth in a Finite World (the detail studies related to Limits to Growth), which can be used as a source for illustrative problems and applications in systems dynamics, and a set of lecture notes and exercises, "Principles of Dynamic Systems" which Meadows used in the introductory systems dynamics course at the Sloan School during the spring term, 1972. (Vuegraphs and other related instructional material can be obtained) When they arrive from Copenhagen, Meadows will forward a copy of the 300 page outline/notes he used in conducting a 2-week seminar for a group of European industrialists last month. He provided copies of several reprints and monographs which he thought might be useful.

Prof. Meadows has been very active, and the tempo may be increasing. He noted that he was MIT's only PhD graduate in systems dynamics. (I believe he said his other major fields were R&D management, operations research, and management information systems.) In addition to having taught at MIT he headed the Club of Rome project which resulted in three publications thus far: Limits to Growth, Toward Global Equilibrium, and The Dynamics of Growth in a Finite World. He helped conduct a systems dynamics tutorial seminar for a NATO group (sponsored through the NATO science activity) and will conduct a two week seminar in systems dynamics at Dartmouth this Fall for senior government officials. During his 14 months at Dartmouth he has initiated the establishment of a Research Center which will emphasize systems dynamics applications, not further theory development. He noted that the methodology now available is quite adequate, but that there was one area which was troublesome, i.e., introducing (mapping) opinion, intuition, or subjective judgments into the systems dynamics model in a systematic manner. He is currently working along Delphi lines, but thinks Delphi so slow and cumbersome that it is diffucult to maintain participant interest.

Prof. Meadows described a number of current activities reflecting the growing interest and application of systems dynamics methodology.

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In addition to the teaching, the Research Center, and the seminars previously mentioned, Meadow's group is developing a regional model for Vermont (the Vermont government is apparently very receptive and an interested sponsor is supporting the work), and a more extensive study is being outlined dealing with the total U.S. energy resource problem (some partial studies have been done in the past, e.g. "The Discovery Life Cycle of a Finite Resource: A Case Study of U.S. Natural Gas," by Roger F. Naill (who is currently with Meadows at Dartmouth) in Toward Global Equilibrium). An International Conference (seminar?) in systems dynamics is being organized to be held at Dartmouth this year. Broad interest and attendance is anticipated.

Others briefly contacted at Dartmouth were Roger Naill and Prof. Meadow's secretary, Donna Brown.

Pugh-Roberts Associates

Pugh-Roberts Associates, Inc. 5 Lee Street, Boston, Mass.

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This consulting firm was established ten years ago by two of Professor Forrester's MIT colleagues: Alexander L. Pugh III, who developed the DYNAMO program generally used in systems dynamics, and Dr. Edward B. Roberts, an early student of Forrester's who remains, like Pugh, on the MIT faculty.

Our discussions about Pugh-Roberts capabilities were with Henry B. Weil, Vice President, and Gary B. Hirsch, Senior Consultant.

Although the firm is small (about six full-time professional staff) the qualifications of the staff is excellent--probably unique--with respect to systems dynamics background and practical application experience.

Pugh-Roberts is clearly opposed to undertaking work in which they take over a problem, design and test a model, and crank out comparisons of alternative policies. They see their role as limited to first assuring a working level of competence in systems dynamics in the organization they are assisting, and thereafter providing advice and assistance to the organization as it develops its own representation, or model, of their problem. They feel that this approach best exploits their expertise in systems dynamics and the expertise and experience of the organization in identifying the important parameters and relationships in the problem to be studied.

They have conducted one week seminars in systems dynamics to provide a rudimentary knowledge of the methodology, and they have worked on a wide variety of economic, social, regional, etc., model development programs. They have done extensive work in extending DYNAMO, e.g. developed proprietary enhancements of DYNAMO, developed a gaming simulation language, and developed a FORTRAN precompiler for DYNAMO.

They provided brochures describing the company's past experience in detail, resumes of the staff members experience, and ball-park estimates of consulting and CPFF fees for assisting in the conduct of courses or model development.

Jay W. Forrester

Jay W. Forrester, Professor of Management, Sloan School of Management, Massachusetts Institute of Technology, Boston, Mass. 02139,

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STAT [redacted] Prof. Forrester was most cordial, willing to assist, enjoyed passing along his philosophical concerns with his technical opinions, and gave no indication of wanting to terminate our visit until he had to leave to attend another meeting. Tea and cookies appeared after about an hour of discussion.

Prof. Forrester is the inventor and principal developer of the systems dynamics methodology. With him throughout our discussions was Naren K. Patni who Forrester introduced as, "My colleague." I believe that Patni is President of Wright-Allen Press, the publisher of most of Forrester's books, and he is also identified with the Forrester Consulting Group, Inc.

Prof. Forrester reviewed the tentative course outline and suggested a few revisions. In particular, Forrester feels that it is important to instill early in the course the notion that the systems dynamics methodology leads to new perspectives toward systems that cannot be achieved through conventional approaches. He gave some examples of the slow, but eventual, acceptance of the methodology by various people and groups with which he has dealt. He recommended that efforts be made to instill the notion of the new perspective concurrent with the development of illustrative applications during the conduct of the course.

In regard to assistance in the conduct of a course, or later consulting assistance, Forrester pointed out that the requests for such assistance are now heavy, and becomming more so--there just aren't enough good people with experience to go around. He suggested that we might like to consider [redacted] STAT

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Forrester was especially interested in the need of the Agency for long range outlooks--say, 10, 20, or 30 years-- His long experience has convinced him of the necessity for paying more attention to the longer range impact of present policy decisions. He said, for example, that the notion that political leaders and depressed minorities would consistently opt for the short term gain over the long term consequences just wasn't true--that, in fact, these groups generally turned out to be the most enthusiastic supporters of the realism provided in systems dynamics analyses--even though the methodology wasn't understood very well.

Professor Forrester is concerned about the need, therefore, for an institute dedicated to training Congressional staffers, senior civil service, and other government managers and executives in the possible uses of systems dynamics. We mentioned the Federal Executive Institute as one possibility that he might like to consider as a source of support for such work.

At the present time Professor Forrester is heading a group developing a comprehensive, detailed model of U.S. economic growth with particular emphasis on inflation. The work has been supported by the Rockerfellow Fund (Foundation?) and should be in the initial test phase by this Fall. Forrester described the model as having about 30 to 40 times the detail of the world dynamics model--and this gives him concern. He said that even the world dynamics model with its high level of aggregation was still too complex for many to grasp, and consequently he believes that the U.S. model will reach only a limited audience. Of special importance, the model is designed to be generally applicable to any country providing the necessary parametric adjustments are made.

In response to a question about the development of universal, or generalized, models, Forrester stated that he thought such developments could be very useful in comparing different national economies, etc. since the use of common models would serve to focus attention on the basic elements responsible for the differences in economic growth, performance, etc.

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Toward a Science of Social Forecasting

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Toward a Science of Social Forecasting*

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Introduction

'oday the United States is searching for improved policies n energy production, population growth, rural development, icome distribution, foreign relations, and other important ocial areas. It will take decades to work out such policies and o implement them, and decades more to assess completely ieir consequences. Should the policies prove ineffective or ndesirable, the process of revision will require still more years.

In spite of these delays, the political and economic institutions that make most social choices are structured to give ttle weight to the consequences of their actions more than few years into the future. Politicians are mainly concerned ith those outcomes of their decisions that may appear before e next election. The normative and descriptive models of ur economy generally disregard the delayed, nonlinear, and reversible nature of the consequences that may derive from a olicy. As a result, most of our society's actions are based xplicitly upon a concern for only the next 5–10 years.

This myopia is reflected in the lack of any systematic fort to develop a comprehensive view of our society's long rm evolution. The Council on Environmental Quality rently conducted an informal survey of forecasting efforts by overnment agencies (1). The survey found that some agencies, ich as the Council of Economic Advisors, make no attempt comprehensive projections of social and economic changes ore than 5 years into the future. Interestingly, the Soviets ave assigned an economist to make comprehensive forecasts the United States' society in the year 2000. However, this onomist complained recently that he is the only specialist his institute who has been unable to find a counterpart in e United States.

If an ocean liner takes 5 miles or more to change course, e cannot successfully steer it on the basis of information ly about obstacles a few hundred yards ahead of it. Inead, radar or some other mechanism must be used to proct the course and the speed of the ship well ahead of its inimum maneuvering distance. Because it may take 30 years or more to alter the course of economic, social, and political institutions, society also needs some form of projective process which will indicate necessary changes well in advance of the time they must actually be effective. We need to develop a social radar function that encompasses the full set of important interactions and whose time horizons are commensurate with the inertia of our institutions.

During the past 2 years I have directed a group of scientists and students at M.I.T. in a preliminary forecast of the long-term consequences of global population growth and economic development. Drawing on that experience, I want today to:

(i) Describe the cause for concern over the lack of adequate long-range social forecasting methods.

(ii) Indicate several minimum requirements for the new forecasting techniques we need.

(iii) Point to some of the unanswered questions about the mechanics and the ethics of the process through which formal models of social systems are used to influence the development of social policy.

I hope I will leave you with the impression that the development of improved methods for long-range social forecasting is a legitimate and urgent area of scientific investigation.

Three characteristics of the global system

The results of our research on current growth patterns are summarized elsewhere (2). The basis for our conclusions can be found in three dynamic characteristics of the human socioeconomic system. These characteristics emerge most clearly when the globe is viewed as a whole, but they are also true for each individual nation.

First, most physical attributes of the global system are characterized by exponential growth. Population, mineral resource consumption, pollution generation, and food production are all examples of major global elements that are currently growing exponentially at rates unprecedented in human history. Current rates of growth would lead the world's population and food production to double in about 30 years; annual rates of resource consumption and pollution generation would double in 17 and 13 years, respectively (3). Of course, current growth may not continue at such rates. Nevertheless, it remains true that numerous social institutions promote and

* This discussion is abstracted from a presentation on forecasting methodologies before the Committee on Science and Public Policy the National Academy of Sciences.

profit by physical growth, and it is unlikely that global growth rates will change very rapidly.

Second, the earth's finite

capacity of the ecosystem to absorb material emissions place some limits to material growth. Should the unabated growth of any physical quantity press on one of these limits, it could impose unacceptable costs on the global society. The concept of a limit to material growth is imprecise, for the nature of any limit depends in a complex fashion on the available technology, and on the magnitude, composition, and geographical distribution of the existing material flows. Nevertheless, most people accept as axiomatic the notion that no material quantity can continue to grow indefinitely on a finite planet. Any sustained material growth trend will eventually deplete a finite resource stock or precipitate the collapse of some important natural ecosystem.

To state as an axiom that material growth must stop is not, of course, to suggest that human progress must stop or even to imply that global economic production must eventually stagnate. Human activities include many functions that are not material intensive. Education, basic research, athletics, social development, and cultural activities of all kinds can continue to expand more or less indefinitely, even after the use of materials comes into balance with the finite environment.

Third, there is typically a very long delay in the effective response of society to any problem associated with material and population growth. The delay arises in several ways:

(i) It may take many years for the growing quantity to cross a threshold above which its costs begin to outweigh its benefits.

(ii) Because our information about the functioning of complex systems is incomplete, several years may elapse before the cause of the increasing costs is perceived.

(iii) Since there are both costs and benefits associated with most activities, and since different individuals, institutions, nations generally receive the costs and benefits unequally, it will often take many years to obtain agreement on the need to respond to some problem.

(iv) Once action is agreed upon it may take years to develop alternative technologies or to make the economic investments and institutional changes needed to reduce the magnitude of a material flow.

(v) Finally, the physical and biological processes of the globe have a certain inertia. The response of the environment to a change in man's materials use is not immediate.

The global response to DDT usage illustrates the nature and the magnitude of these delays. The global use of DDT as an insecticide was initiated in 1940. It took several years for the level of use to rise to the point where observable biological damage began to occur to species other than the target pests. Not until about 1960 was significant public attention focused on possible harmful consequences of widespread DDT use. Even in the United States, where economic and technical factors favor the use of alternative pest control methods, it has taken until 1972 to ban DDT from most uses. Poorer countries are still very far from adopting similar bans. Finally, even when DDT usage begins to decline, its levels in the marine environment will continue to rise for several years because of the delays in transmission and degradation of the chemical. One study suggests that if we were to begin decreasing the use of DDT today so that global application of the chemical declined linearly to zero by the year 2000, levels of DDT in marine fish would continue to rise for about 10 [...] more than current level until 1995, and would still be present in significant amounts in the year 2020 (4).

Similar delays exist in most other sectors of our global system. For example, after more than 20 years of strenuous development, fission power sources still provide only a fraction of 1% of the total United States power needs. Even after the average family size declines to replacement level, about two children per family, it will take the population 70 years to stabilize.

These three dynamic characteristics of social systems, a rapid rate of physical growth, limits to physical growth, and long delays in social response to changing conditions, have serious implications. Any engineer would recognize those three conditions as sufficient to introduce a pronounced tendency toward system instability. A growing system characterized by these three conditions will tend to expand beyond its ultimate limits, in a behavior mode we call "overshoot," and eventually fall back to a sustainable level. If, during the period of overshoot, the overloaded resource base is consumed, eroded, or otherwise degraded, the final sustainable level may be greatly decreased.

Possible ways to reduce instability

The above analysis indicates three possible ways of decreasing the instability of our growing socioeconomic system, one directed toward each of the three dynamic characteristics that produce the potential for instability.

One approach is to raise the effective limits to population and economic growth through technologies that allow more efficient use of resources or create less harmful impact on the environment. Such technologies can easily be envisioned and some have been developed, although historically technologies have usually been developed to meet other goals and have tended to be environmentally destructive. Raising effective limits by technological advance does not make the system inherently more stable; in fact, it may ultimately make the magnitude and the consequences of an overshoot more severe. However, technologies that conserve materials would provide time to make more permanent system adjustments; therefore, such technologies are to be encouraged.

A second approach to system stability would be to decrease the rate of physical growth, through deliberate social and economic changes. The goal of such a process would be a stable population and an economy based on a constant flow of energy and materials. Ultimately, ending growth is the only viable policy on a finite planet, but it is an extremely long-term policy, which can only be planned and implemented on a time scale of 50–100 years. Thus, while this approach should be adopted, it must be augmented.

A third way to decrease the probability and magnitude of a physical overshoot is to reduce the length of system delays. This approach has only a limited range of application, since many physical and biological delays are fixed—for example, the time it takes for populations to age, pollutants to be degraded, or radioactive materials to decay are essentially outside of our control.

However, many *social* delays could be circumvented if policies could be based on anticipation of social needs, rather than on responses to them. Today, we typically evaluate a policy by examining the costs and benefits it has yielded in the past. Were we to shift from historical analysis to projective planning, we would [illegible] benefits could be expected 20 or more years from now if a new policy were implemented. With the availability of suitable projective techniques for evaluating the future costs and benefits of a decision, the projective approach would serve to decrease many of the social response delays in the system.

Of course tentative efforts are already being made to develop improved forecasting methods. There is a significant difference between the "try it and see" attitude implicit in the decision to use DDT back in 1940 and environmental impact statements we now require before certifying new pesticides. Unfortunately, in spite of recent efforts, most areas of social decision making still use no formal long-range assessment techniques in choosing among alternative policies. This is true, at least in part, because we have no generally accepted techniques for projecting the social consequences of our policies. Therefore, given the fact that our policies do have important, long-term implications for our social, economic, and ecological system, we should assign a high priority to developing the appropriate forecasting methodologies.

Requirements for a new forecasting methodology

To be useful, new social forecasting methods must have several features. First, they must be able to integrate into one conceptual framework information that ranges in precision from intuitive perceptions to controlled measurements of physical systems. There already exists a great amount of information about the determinants of long-term societal evolution. However, our confidence in the various pieces of that information varies widely, perhaps by several orders of magnitude. Many of our current analytical methods require data that are more numerous or more precise than those typically available. These methods are thus unable to deal with many of the more important long-term problems.

If we wish to understand the behavior of total systems, we cannot ignore several relevant areas simply because the data are in a form that cannot be handled by our particular methods of analysis. Social changes come through the interaction of demographic, economic, technical, cultural, and other factors. When we ignore elements in one or more of these areas, we may overlook the fundamental cause of the problem. Instead, we should incorporate into our studies the best information available, whatever its form or precision. Of course, care must also be taken to test the potential impact of errors in the data on the conclusions derived from the analysis.

Second, the analytical frameworks we need should provide a neutral vocabulary that permits professionals from many different fields to cooperate directly in pooling their knowledge. No demographer, no economist, no political scientist, no engineer can make by himself the forecasts we need. The behavior of social systems comes from the interactions among variables that are included within the bounderies of many different traditional disciplines. To study short-run phenomena, professionals in one discipline often can usefully consider most of the influences from factors outside their discipline to be exogenous or constant, and then they can restrict their study only to the factors within their area of specialty. Over the longer run, however, the interactions of real systems fail to confine themselves to man's artificial boundaries. Interdisciplinary factors are not constant and cannot be excluded from explicit analysis. Unfortunately, the vocabulary, paradigms, and analytical methods of one profession are generally not shared by others. Interdisciplinary research has often taken the form of one person acquiring information from many others, then attempting to distill out everything relevant to a particular problem, and finally incorporating the accumulated information into an analytical methodology from his own field. The inescapable preconceptions and values inherent in any one professional's outlook on the world make that approach far less than an optimal procedure. We need general methodologies that can be understood and used by people from many different professions.

Third, we require a philosophy of system structure that acknowledges the complexity, the nonlinearities, the delays, and the tenuous causal relationships that determine the behavior of real-world systems. Associated with that philosophy should be analytical techniques that can accommodate such mathematically difficult relationships.

Finally, we need a new theory of inference and a set of formal techniques that will permit analysts to assess the confidence that may be assigned to conclusions derived from complex, nonlinear, underidentified, simulation models. At the moment, we have well-developed procedures for assessing confidence intervals only for the results of a limited set of models based on some rigid mathematical prerequisites. These procedures cannot be applied to the nonlinear and complex models needed to represent the total behavior of large social systems.

In the absence of formal validation techniques, we rely on the qualitative and subjective interpretation of sensitivity analyses to determine whether the results of a model study are insensitive to error. When it is found that no member of a reasonable set of changes in underlying assumptions leads to different conclusions, then it is declared that more confidence can be placed in the model. This is not a satisfying mode of validation for someone who has come from a background in the physical sciences, and it is a poor basis for social choice. The validation techniques we need are probably some combination of formal control engineering methods with the statistical formalisms that have been developed in the field of econometrics.

It is important to recognize that methods which will meet the above requirements are not simple extensions of techniques currently used in the natural sciences. The natural sciences have advanced through reductionism by isolation of individual elements of a system, control of exogenous influences on their behavior, and then systematic variation of a few "independent" variables to measure their influence. There are very few truly "independent" variables in social systems, and the problems of interest often come from the simultaneous interaction of all the parts. The techniques we require must be holistic—based on the recognition that social change does not depend on the attributes of a single factor, but on the interaction of many.

Models and the process of social choice

Even when we have developed modelling methods with the above characteristics, we will not have provided society with an effective social radar. The nature of human and social decision making will prevent any form of formal model from directly making decisions. Policies are set and decisions are made through the interaction of many individuals as they assess the possible consequences of alternative actions and compare the expected costs and benefits of each possible outcome. Formal models can only assist in the first half of that decision process, establishing what *could* be. Deciding what *should* be—i.e., exercising social values—will remain the perogative of individuals and the institutions that represent them. Thus, we must view the nature of social decision making, even with vastly better models than are available today, as a process through which the formal model of the system analyst complements the value system and verbal models of the decision maker. Using verbal models, social policy makers may identify appropriate problems. With formal models, system analysts may determine the possible consequences of alternative responses to the problem. Finally, the subjective judgment of those involved in the outcome can be used in picking from the possible outcomes those that most satisfy social goals. This cooperative process between verbal and formal models involves many stages that are still poorly understood. Thus, an important focus of research on improved models would be the process of model development and use.

The above comments have been general in nature. To conclude this statement, I would like to present a specific agenda for research, one I compiled while working with several system analysts from the United States, Europe, and the Soviet Union, to identify the unsolved problems in developing and implementing improved social system forecasting techniques. The questions pose a challenge to all who are interested in increasing man's understanding of his own complicated social systems.

QUESTIONS ABOUT MODEL DEVELOPMENT AND USE

Managing model construction

(*1*) How could one categorize social goals to obtain a list of questions that could be addressed through simulation model studies?

(*2*) Is there any set of personal characteristics that one could use to identify persons who are more likely to make useful models?

(*3*) Is there a typology one could use to decide which kind of models a specific decision maker might find more useful?

(*4*) What rules can be used to manage a large team of scientists in the efficient construction of a model that requires inputs from several different disciplines?

Designing the model

(*5*) A model on the computer interacts with mental models of the analyst and the client. What procedures and hardware would best facilitate this interaction?

(*6*) What formal rules can be used to decide whether a given model should be more or less aggregated?

(*7*) How can hierarchical techniques be used to develop a set of models that deal with related aspects of the same system?

(*8*) What is the most efficient way to identify that part of the model which is most in need of improvement?

(*9*) What formal procedures can be used to use sensitivity analyses and information on the statistical properties of the coefficients in the model to provide an objective measure of confidence in the model results?

Estimating model coefficients

(*10*) How can we improve the process through which an[illegible]ments on the real world?

(*11*) When expert opinion is the best available source of information on model relationships and coefficients, how does one evaluate the relative utility of alternative experts, and how does one develop the "best" coefficients from the opinions of several experts?

(*12*) What precautionary measures must be used when linear statistical inference techniques are used to estimate the coefficients of a nonlinear model?

(*13*) What places does a computer model potentially have in the total process of individual or societal decision making?

(*14*) We must recognize that the analyst and his model are both part of the system the analyst is studying. What ethical and procedural rules should govern the use of models to advocate some change in social policy?

(*15*) What are the cost/benefit implications of advocating change in an existing social system on the basis of current models, rather than waiting until a better set of models is available?

(*16*) How does one include in the model the indices of performance which will permit the decision maker to pick the preferred of several alternative system behaviors?

(*17*) How can the decision maker identify the best of several alternative models?

Until recently it has been possible for most individuals, particularly natural scientists, to regard social systems as outside the realm of predictive science. However, the availability of computers that can handle complex models and the urgent need to put current actions in the context of their future consequences suggest we should change that attitude. Relatively little effort is now invested in the development of long-term forecasting methodologies, yet the effectiveness of many current decisions will be impaired without a longer-term view. The requirements and questions posed above are subject to systematic investigation. Certainly the fruits of the research could equal that from other areas of scientific endeavor. It is time to begin in earnest the development of improved social forecasting tools.

1. Council on Environmental Quality (ed.) (1972) *Summary of Long-Range Forecasting Activities Performed by the Federal Agencies*, August 11, 1972, Interagency memorandum.
2. Meadows, D. H. *et al.* (1972) *The Limits to Growth* (Universe Books, New York); Meadows, D. L. & Meadows, D. H. (eds.) (1972) *Toward Global Equilibrium—Collected Papers* (Wright-Allen Press, Boston, Mass.), in press; Meadows, D. L. *et al.* (1972) *The Dynamics of Growth in a Finite World*, forthcoming.
3. The U.S. Bureau of Mines projects that the world's primary demand for minerals may increase annually by 3.6–5.5%. This forecast is equivalent to a doubling time of from 20 to 13 years. U.S. Bureau of Mines (1970) *Mineral Facts and Problems* (U.S. Government Printing Office), p. 3; [Time series on pollution emissions are poor or nonexistant in most cases. However, energy production and, therefore, thermal emissions are crude but useful indices of overall pollution. Thermal wastes were projected by the SCEP study to increase globally by 5.7% per year. (1970) *Man's Impact on the Global Environment* (M.I.T. Press), p. 64.]
4. Randers, J. (1972) "System Simulation to Test Environmental Policy: A Sample Study of DDT Movement in the Environment," *International Journal of Environmental Studies*, London, England, November 1972.

A Summary of Limits to Growth -
its Critics and its Challenge

Donella H. and Dennis L. Meadows

This discussion was originally presented at Yale University, September, 1972, in the School of Forestry's symposium on limits to growth. An extended version of the text appeared in Futures, February 1973.

Introduction

Over the past two years we have worked with a group of scientists and students to understand the long-term causes and consequences of growth in the globe's population and material output. From our research we have been led to conclude that current growth rates cannot be sustained even for the lifetimes of the children being born today. If society maintains its current reliance on growth to solve short-term problems, we believe that population and material production will grow past sustainable limits, that the carrying capacity of the earth will be eroded, and that there will then be an uncontrolled decline in population and economic activity. However, this outcome does not appear inevitable. Mankind could instead begin to assess realistically the limits to material growth. Society's goals and instituions could be altered to reduce growth now and to move ultimately towards an orderly accommodation with the finite constraints of the globe. If these changes were made, it would probably be possible to sustain the world's population more or less indefinitely and to provide for all its basic needs.

Our view of growth and its consequences were developed through the constructi of World3, a mathematical model of the physical, biological, psychological, geological and other causes underlying growth. Many objections have been raised to our approach and results. In this presentation we would like to describe the history of our work, to summarize the basic foundations of our thesis, and to respond to the most common criticisms of our conclusions.

Historical Summary

With the publication of World Dynamics[1], Professor Jay W. Forrester challenged the world's scientists and decision makers to extend their time horizons and to examine in holistic fashion the long-term causes and consequences of growth in the world's population and material output. To contribute to analysi and understanding of global problems Forrester proposed a formal model of the interactions among population, capital, and several factors that influence their growth: food, resources, and pollution. Recognizing that his model was not perfect or complete, Forrester emphasized that no perfect or complete model exists, and that the models on which decisions are now based are not even explicit enough to be discussed and improved:

> In spite of the tentative nature of the world model described here; various conclusions are drawn from it. Man acts at all times on the models he has available. Mental images are models. We are now using those mental models as a basis for action.
>
> It is hoped that those who believe they already have some different model that is more valid will present it in the same explicit detail, so that its assumptions and consequences can be examined and compared. To reject this model because of its shortcomings without offering concrete and tangible alternatives would be equivalent to asking that time be stopped.
>
> (World Dynamics, p. ix)

In order to facilitate the development of improved long-term global models, our group has since prepared three additional documents on the dynamic implications of physical growth in the global system. In World Dynamics, Professor Forrester described the basic objectives of the world modeling effort initiated by the Club of Rome and presented the structure of a preliminary model called World2. This model was subsequently expanded by our team and related more thoroughly to empirical data. The revised model was called World3. (Henceforth, when we are discussing a point that applies to both World2 and World3, we will speak simply of the World models.)[1]

In Limits to Growth, we described several attributes of growth in population and material output; attributes that give the world system a tendency toward unstable behavior.[2] We proposed material equilibrium as a sustainable alternative to the goal of perpetual growth that is the implicit basis of most contemporary policies.

Thirteen short papers that discuss the history and the implications of our project and that describe the detailed simulation submodels underlying the World models were published in the technical literature. They have now been collected into a third book, Toward Global Equilibrium: Collected Papers.[3]

Our technical report, The Dynamics of Growth in a Finite World, is the fourth and final report on our work for the Club of Rome.[4] This technical report presents the assumptions, equations, and data underlying World3 and analyzes the model's behavior under alternative assumptions.

Foundations of The Limits to Growth

The Limits to Growth (henceforth referred to as Limits) deals with fundamental properties of the world system such as exponential growth, finite limits, and feedback delays. These properties are the real basis of our concern about physical growth, and they can be understood and discussed independently of the precise numerical assumptions of any model. In fact it was to call attentio these dynamic properties, rather than the model equations, that we presented to a nontechnical audience in a publication separate from the technical mode description. We shall summarize here the five main points from <u>Limits</u> and discuss critical responses to them.

1. <u>Exponential growth is an inherent property of population and industr capital but not of technology</u>. Population and material capital grow exponent by the very nature of the reproductive and investment processes. This is not an arbitrary assumption, it is a fact derived from empirical evidence and knowledge of underlying causes. New people can only be produced by other peo and machines and factories are needed to generate other machines and factorie Whenever the change in a quantity depends on the quantity itself, the change tends to be exponential in form. The numerical exponent, or the rate of growt varies, both in the real world and in the World models. The growth process is nevertheless, inherently exponential.

It may be true that human knowledge is also inherently exponential; knowledge can aid in the accumulation of more knowledge. However, it does not follow that any given technological application of that knowledge is inherently exponential. To bring a new technical discovery into widespread use requires social recognition of the existence of a problem. It may also require that new institutions be established, often at the expense of the old, and that investment be diverted from some other possible use into physical capital that embodies the new techniques. Social perception and consensus, institutional change, and the diversion of capital to new needs are <u>not</u> inherently exponential

Discovery of oil is not in the long run made easier by the fact that certai fields of oil have already been discovered. The next increment of pollution abatement is not directly facilitated by the increment that went before. One doubling of land yield does not enhance the possibilities for the next doubling. Any suggestion that these "exponential" technologies are inevitable is based on a profound misunderstanding of the inherent cause of exponential growth. The suggestion also implies a rather sweeping disregard for the social basis of technological change, the second law of thermodynamics and the law of diminishing returns.

2. <u>There are physical limits to population and capital growth.</u> The World models are built upon the Malthusian assumption that the earth is finite, and that some change in current exponential growth processes will thus be necessary to accomodate man's physical presence and activities to the earth's limits. The purpose of the models is to investigate what kinds of changes might and should occur. We chose to investigate a Malthusian view of a limited world because our own impressions and much empirical data suggest that the world is finite in several important ways. It seems to us not only more realistic, but more socially responsible and more useful to investigate the ways in which society might adjust itself to earthly limitations, rather than to assume away all such limitations.

The World models express the idea of the earth's limits through four explicit assumptions: there is a finite stock of exploitable nonrenewable resources, there is a finite capacity for the environment to absorb pollutants, there is a finite amount of arable land, and there is a finite yield of food obtainable from each hectare of arable land. No one has exact information about where these limits are. In fact it is probably impossible to express any one of these limits by a single number since they all vary with time. We know that to a certain extent they are expandable by technology. We also know that they can be reduced by misuse.

By attempting to represent the world's limits and the growth of the physical system toward them we did not expect to gain any more precise information about the location or values of the limits themselves. We did try to achieve two other purposes. First, we sought a framework in which many growth processes and limits could be considered together, to illustrate that solutions proposed for any one problem related to growth are meaningless without considering the system as a whole. The traditional approach of specialists in any one area, for example, resource economics, food production, or environmental deterioration, amply illustrates how easily any single resource, food, pollution, or population problem can be mentally "solved" by assuming that sufficent capital, energy, labor, land, material and time can be allocated to that one problem. Because they are holistic, the World models force one to explore the possibility that several of these problems may have to be solved simultaneously. We are interested in that possibility because our perception of exponential growth indicates to us that these problems will not come slowly, one at a time.

Our second concern was to represent not only the forces that can increase the earth's carrying capacity for human activity but also the forces that can reduce it. From our Malthusian point of view, Western man is entirely too pron to rejoice in his newly-irrigated land, underwater oil-drilling rigs, Green Revolutions, and catalytic converters and to ignore the eroded, salinized, or strip-mined land, the dumps of wasted resources, the depleted ore bodies, the simplified ecosystems, and the deprivation of other humans in other cultures that he leaves in the wake of his "progress". The World models contain assumptions of possibilities for considerable future progress, but they also take into account mankind's fallibility. They assume that the limits can be pushed downward, as well as upward, by man's activities.

There are, of course, other limits we have not included in the World models The most obvious omissions are the limits to the sustainable rate of use of renewable resources - fresh water, timber, fish, and game for example. We also recognized the importance of social limits, but omitted them from specific analysis. We stated in Limits (pp. 45-46) that social limitations (unjust distribution, waste, wars) would only decrease the possibilities for growth allowed by physical limits.

3. There are long delays in the feedback processes that control the rate of physical growth in the world system. Delays are the main source of instabilit in the global system. When rapid growth is coupled with a long delay between cause and effect, the growth may proceed far beyond sustainable limits before the effects that can stop it come into play. We have not assumed that mankind is unresponsive to the changing situation around him. We have simply assumed that social institutions respond only to situations about which they have information, that the information they act on is often incomplete and late, and that the social response is not immediate but is itself delayed. The response delay can be caused by political, physical, or biological processes. It is increased by the time required to invent/construct/test/perfect new technologies. Many response delays are beyond control, such as the delays inherent in the population age structure or in the propagation of persistent materials through the environmer

The combination of three major assumptions causes the "overshoot mode" of the models: the assumption of feedback delays, the assumption of limits to the earth's carrying capacity, and the assumption that the human value system will promote population and material growth until counteracted by very strong forces. When, in the "equilibrium" mode, we assume a change in man's value system in favor of stability and against sustained population and capital growth, the overshoot no longer occurs. The overshoot could also be eliminated, or minimized, by assuming that the society can avoid the implications of delays by conducting accurate long-term planning. Of course our purpose in publishing Limits was to encourage both the value-change and the long-term planning processes.

4. There are two possible social responses to the limits to growth; weaken growth forces or remove the symptoms of impending limits. The common response of modern social systems to the pressure caused by limitation of any resource is to remove the pressure so that growth can continue. Highways are jammed; build more highways. Copper reserves are depleted; import copper. Electric power is insufficient; develop nuclear power plants. People are hungry; buy fertilizer.

It is only very recently and very weakly that an alternative set of solutions has been seriously proposed; reduce the use of automobiles, use less electric power, extend the useful lifetime of material goods, have fewer children. This second set of responses recognizes that the problem to be solved is not scarcity of a specific resource; highways, copper, power or food. These scarcities are symptoms, or signals, of the underlying problem; population and material growth against a finite resource base. The first set of responses serve to remove temporarily the adverse symptoms of growth. If they are not accompanied by responses of the second type, that weaken the social values causing growth, further growth will eventually cause different resource scarcities. These scarcities will call for additional technological solutions to remove the signals of impending resource limits. The real danger of responses of the first type, responses that ease the symptoms of the problem is that they are often used to discourage responses of the second type, those that control growth itself. The more successfully the signals of resource scarcity are masked and denied, the more likely it is that the necessary social value change will come too late.

velopment of technology. Combined with the necessary value changes that will control physi growth, carefully selected new technologies can create magnificient possibilit for human society. We are, however, concerned that technological successes have almost invariably been used to enhance, rather than reduce, the strengths of the positive population and capital feedback loops that drive the global system. We do not oppose technology. We do oppose the present trend of technological "progress" that is not only poorly guided by social wisdom or restraint, but is used as an excuse not to develop that wisdom or restraint.

5. <u>The equilibrium state may be a desirable option, wherever the limits to growth may be</u>. It is not necessary to agree with the World models or to believe in the imminence of any physical limits to growth to become intrigued by the nature and potential of an equilibrium state. An equilibrium state is a society that has stabilized its population at a desired level and that supplies its material needs with a minimum throughput of nonrenewable, pollutic creating resources. <u>Limits</u> ends with a rather Utopian description of such a state. We sincerely believe that some form of deliberate material and population equilibrium is attainable, not immediately,but within a generation or two. We also believe that the exercise of understanding and planning how su a state might work is both exciting and useful in that it might provide the realistic, sustainable, long-term goal that is now lacking in nearly every part of world society. It seems impossible to us that material growth can be successfully controlled unless there is some well-defined goal towards which it may be directed. There is no way of deliberately changing the composition of growth or its distribution unless there is a clear vision of what growth is for The specifics of the goal will change and develop as more is learned about the world. We feel that it is only important to have such a goal and to keep it consistent with present knowledge.

The idea of a physically non-growing society is so foreign to some people that they have invested the idea with some strange mental models of their own. They have suggested that an economy at material equilibrium must be stagnant intellectually or technologically; that it must be rigid and dictatorial; that it must preserve the present maldistribution of resources or income. We have already suggested in <u>Limits</u> that we would expect just the reverse. We would hope that more imaginative respondents will accept the challenge of thinking through the economics and sociology of a physically stabilized state.[5] We suspect that the exercise would be more than theoretical; that it would illuminate some of the current economic and sociological problems of a growing state as well.

We have not suggested in Limits or elsewhere that the equilibrium state should be attained immediately, or that physical growth should be brought to a sudden halt. On the contrary we have pointed out long delays in the social system and the necessarily gradual nature of demographic change, and we have suggested that an orderly shift to equilibrium from present rates of growth may take as long as 100 years. Thus although the first steps toward equilibrium should be small ones, they should be taken soon. A good beginning might be a common recognition that physical growth cannot be forever substituted for the social resolution of difficult choices.

In summary, we believe the basic points of our modeling effort, as described in Limits, merit consideration even though none of them can be supported by rigorous proof. No social model can be rigorously proved true. Together these points constitute a holistic hypothesis about the world system that is generally consistent with real-world observations. We do not believe that the same can be said for the mental models on which important decisions with long-term implications are currently based.

Price, Technology, and Values

Let us turn now to the three mechanisms that many critics of Limits believe will allow mankind to sustain and control material growth without any changes in the current system - price, technology, and social value change. All three are actually included in the World models, but in implicit and oversimplified form. Of course all three are important, complex, dynamic subsystems in themselves. We will describe here, very briefly, how more complete representations of these subsystems might be constructed. However, none of the added details would alter the basic conclusions of our work.

Economic price is a function of two socially determined variables---the current value society places on a certain good or service and the apparent cost of supplying that good or service. Economists postulate that the long-term stabilizing role of price in a growing system is to signal resource scarcity. They point out that price changes guide social values and the economic system so that the declining supply of a scarce resource is utilized more efficiently.

When increasing scarcity causes the price of some material to rise, numerous social responses may be triggered. There may be a more intensive search for natural deposits of that material, or increased recycling of discarded products containing it. Food shortages leading to rising food prices may stimulate farmers to adopt more efficient methods of production, governments to irrigate more land or people to eat less food. These dynamic effects of the price mechanism will indeed influence the way in which a growing system approaches its physical limits.

World3 contains several causal relationships between the real supply of some economic quantity (such as food, nonrenewable resources, industrial capital, service capital) and the response of the economic system to scarcity of that supply (develop more agricultural land, allocate more capital to resource production, increase investment rates). These relationships are most realistically represented with price as an intermediate variable:

decrease in supply ⟶ rise in price ⟶ social response

In World3 we have simplified the real dynamics of the price mechanism by eliminating explicit reference to price, the intermediate variable: The representation of the causal chain has been shortened to:

decrease in supply ⟶ social response

The ultimate regulating effect of the price system is thus included, but price does not explicitly appear in the model.

The only purpose of eclipsing the price mechanism in this way is to increase the model's simplicity and understandability. Omission of price is equivalent to assuming that the signals provided by the price system are available to social decision points with a delay that is insignificant on a 200-year time scale. To check the validity of this omission, several of our submodels explicitly included price and its effects on technological advance and resource availability. The general long-term behavior of these submodels was similar to that of the World model's resource sectors.

To the extent that prices do not immediately reflect actual resource costs in the real world, the price system will be a source of additional instability in the world system. Instability will also be increased if cost information is transmitted immediately but to institutions that can adjust their production or consumption patterns only after a long delay. In either case, the delay between decreased availability and social response will reduce the stability of the economic system as it adjusts itself to any limit. Thus by assuming in World3 that the price system works instantaneously we have omitted a source of system instability. To the extent that prices are actually delayed signals of scarcity, our model will underestimate the tendency of real economic systems to overshoot physical limits.

We view technology, like price, as a social phenomenon - it is the application of man's general knowledge about the world to the solution of a specific, perceived human problem. If we were to make a complete dynamic model of the development of a given technology, we would include the following:

- a level of accumulating general knowledge, with the rate of accumulation dependent on the resources devoted to basic research.
- a widespread perception of some human problem.
- an allocation of physical resources, human effort, and time to search for a technical solution to the problem, with a realization that the solution may not be found if the level of knowledge is not yet great enough.
- a delay to allow social acceptance and implementation of the new technology, the length of the delay dependent on the magnitude of the required departure from the present way of doing things.
- a representation of the total impact of the technology on the system, including social, energy, and environmental costs.

This model of technological advance might be contrasted with the one advanced in separate papers by Boyd, Cerlemans, and the Sussex group.[6,7,8] Each assumed that technology is inherently exponential and that the appropriate technical capabilities are instantaneously available whenever needed. They have supposed that technological advance costs nothing, requires no capital investment, has no harmful side effects, and encounters no resistance from institutions already present. Not surprisingly, when their representations of technology were inserted in World2, the model grew far beyond the original point of collapse. We would suggest that their theories of technological advan are so completely foreign to anything available in the real world, that their revisions of World2 provide no useful information whatsoever about the real implications of physical growth in a finite world.

Nearly every causal relationship in the World models could conceivably be changed by some sort of new technology. In the past various technologies have, directly or indirectly, improved birth control effectiveness, increased land productivity, and increased the average generation of persistent pollution per unit of industrial output. The advance of technology has created more costly and destructive weapons, increased life expectancy through medical advance, and hastened the rate of land erosion. It is by no means certain that technologies will continue to do any of these things in the future, since the human values and social institutions that govern technological development are always subject to change.

In other words, we view technology as socially-determined, discontinuous, infinitely varied, and delayed. It is nevertheless an important determinant of the functioning of the world system. How can such a concept be included in a world model? Since so many causal relationships might be altered by some conceivable technological change, we had to consider building technological change into each relationship as we formulated it. We did this by assigning possible technologies to three categories; those that are already feasible and institutionalized, those that are feasible but not institutionalized, and those that are not yet feasible.

Some causal relationships have historically been altered by technology and continue to be altered regularly today. These are in areas where there is social agreement about the desirability of change, and where resources and institutions to bring about that change are already integral parts of the system Examples are medical technology to improve health, industrial technology to raise production efficiency, agricultural technology to increase land yields, birth control technology to plan family size, and mining technology to discover and exploit lower-grade nonrenewable resources. A significant fraction of the world's people have adopted the value system that will continue to promote these technologies as long as their costs can be afforded. They are effectively built into the world socio-economic system. Therefore, they are also built into the relationships of the World models, with the assumption that they will continue to develop and spread through the world, without delay, as long as there is economic support for them.

There are other technologies that have not been so widely accepted that they can be considered a functioning part of the world system. It is not yet clear that all the nations of the world are willing to institutionalize and pay for technologies such as pollution control, resource recycling, capture of solar energy, preservation of soil fertility, alternatives to the internal combustion engine, or increased durability of manufactured goods. All of these technologies are feasible, and there are signs of the social value changes necessary to incorporate them into the world system. It is not possible to know when or even whether they will be adopted on a worldwide scale. Therefore we have not assumed them in the model relationships, but we have included many of them as optional functions, which a model operator can "turn on" at any specified time in the future. The model can be used to test the possible impact of any or all of these technologies and the relative advantages of adopting them sooner rather than later.

There is a third set of technologies that is not included in the model at all. That is the set of discoveries we cannot possibly envision from our perspective in time. Of course no model, mental or formal, can incorporate these unimaginable technologies as they will actually occur. That is one reason why no model can accurately predict the future. Any long-term model that is being used to aid the policy making process must therefore be updated constantly to incorporate surprising discoveries as they occur, and to assess how they may change the options of human society.

It is possible, of course, to include in the model the assumption that some unimaginable discovery will come along in time to solve every human problem, including the limited resource base of the earth. Many mental models seem to be based on that assumption. However, our bias as both modelers and managers is to search for understanding and for better policies based on the constraints of the system as it appears now, not to rely on developments that may or may not come in the future.

We have already indicated that both technology and price are dynamic elements directly dependent upon the values, needs,and choices characteristic of the human society. Of course values underlie many of the other dynamic elements of interest in a model of physical growth. In fact the whole socio-economic system might be thought of as a constant interplay of human desires and goals within physical and biological constraints. Therefore, although the World models are not intended to be models of social value change, they must contain some assumptions about the dynamics of human values insofar as they influence and are influenced by the processes of physical growth.

In the difficult task of modeling human values we have tried to include only those most basic values that can be considered globally common. These basic values begin with requirements for survival, such as food, and go on to include a hierarchy of other desires; for longevity, children, material goods, and social services such as education. Some of these values are represented explicitly in the model as variables that have an important influence on economic decisions. Examples from World3 are desired completed family size, and preferences among food, material goods, and services at different income levels. Others are included implicitly, for example in the allocation of service output to health services or in the quantity of nonrenewable resources used per capita.

All of the values included in World3 are assumed to be responsive to the actual physical and economic condition of the system; they are all involved in feedback loops. The patterns of dynamic value change included in the model, however, are limited to the patterns of change historically observed in individual countries over the last hundred years or so. During that time the major force behind value change in the world sytem has been the process of industrialization, a process that is still underway in most of the nations of the world. Therefore the values that both shape and respond to the development of the model system follow the historic pattern of industrialization. As industrialization increases in our model (measured, say, by the level of industrial capital per capita) the aggregate social demand in our model shifts in emphasis from food to material goods and finally to services. Other changes occur in the model in the preferences for children, education, and health care, and in the distribution of various goods and services throughout the industriali[illegible] population.

We have not built into World3 any global shifts in values other than those that might be expected to take place as the world becomes more industrialized. Again, the model cannot predict value changes, but it can serve as a test device to show the results of any given assumption about the future evolution of values. Human values, like human technologies, may evolve in the future in directions we cannot possibly foresee at this moment in history. Therefore we have also included, in several model relationships, test switches that can be used to activate postulated value changes at any date specified by the operator. (Examples of such changeable values are desired family size, fraction of output consumed, and the relative desires for food and services. All of these are changed to produce the model's "equilibrium" runs.) We have used these switches extensively. As we demonstrated in Limits, an appropriate set of value changes can bring the model system into a stable and desirable equilibrium state. That set of value changes is not one that has occurred historically as a result of industrialization in any country. We believe that such value changes are possible to achieve in the future, but only by a concerted and conscious effort. The shift in values that normally accompanies industrialization, the one we might expect to take place if the world continues "business as usual", is the very value shift that leads to the overshoot and decline behavior mode.

The Modeler and his Environment

It has been suggested that the World models arose only because of the sudden widespread concern about the environment in modern western societies. Of course computer models, like any product of man's intellect, must be evaluated as part of the cultural context within which they are constructed. This statement s also true for the mental models of the critics of Limits and for the models it guide current public policy.

Every model of a social system must omit some details of the real world. ification is the essence of model building. A model is constructed to understanding of the nature and implications of complex relationships al world. If the model were identical to the real world in all it would be as difficult as the real world to understand.

> It is a very fundamental principle indeed that knowledge is always gained by the orderly loss of information, that is by condensing and abstracting and indexing the great buzzing confusion of information that comes from the world around us into a form which we can appreciate and comprehend.[9]

Thus even if we had comprehensive and accurate information on all important aspects of the real world, our models would be simplifications of reality.

Human judgment is inextricably involved in the choice of the issues addressed by a model and in the identification of those "unimportant" details that may be eliminated without detracting significantly from the explanatory power of the model. Every model is thus inevitably influenced by prevailing social values and goals. In short, there is no model useful for understanding all issues and no "scientific" or "objective" way to construct a perfect model.

The greatest advantage of formal, or written, models over mental models is that their constituent assumptions are precise and explicit and thus subject to the scrutiny of critics. This is no guarantee against error or against the effects of unwarranted social biases, but it makes the discovery of errors and biases more likely. Most critics of Limits have not defined the bias that underlies their own approach, nor have they presented assumptions explicit enough to be judged by their audience.

The accusation that the World models have been unduly influenced by the prevailing environmental concern seems to imply that the models are addressing random, unimportant, or spurious issues. The latest wave of environmentalism may indeed turn out to be a fad, merely the product of rising expectation, or boredom, or alarmist journalists, or all of these. However, there is an alternate possibility. The current concern with the environment may be a response to a correct perception of a changed external reality. It may be a result of the first glimmerings of human understanding about total systems and the first perception of a real worldwide negative impact of man's activities on the ecosystem. If so, the World models may represent a small manifestation of a healthy social reaction to an environmental change; a reaction that will lead to new values, technologies, and economic prices that attempt to adapt socioeconomic systems to the newly-perceived constraints. In that case the critics, the technological optimists, the foot-draggers who claim that there are no constraints and no reasons to change values from the present pro-growth set, represent exactly the social and institutional delays that tend to destabilize the system and send it shooting past its ultimately sustainable limits.

Growth and Income Distribution

Some critics have rejected the no-physical-growth argument as irrelevant to the "really important" problems of the composition and distribution of growth. As we have already indicated, we find it impossible to view the rate of physical growth, its composition and its distribution as independent or mutually exclusive problems. Human societies will not achieve a more equitable distribution of wealth until they better understand the processes of growth. Historically at least, growth of population and of capital has been correlated with the concentration of wealth and with rising gaps between the absolute incomes of the rich and the poor. We believe that there are at least two basic reasons for these trends. First, physical growth inevitably worsens the resource/population balance. When there are fewer available resources per person, there are also fewer real social options to resolve conflicts of interest. Second, by relying on the false promise of growth, social institutions are able to delay facing the very important and difficult tasks of making social tradeoffs and defining social goals. Until these tasks are squarely faced there will be no real redistribution of income.

The no-growth argument is an appeal for readjusting the composition and distribution of economic output. The pro-growth argument is an attempt to postpone this readjustment; to confer it on future generations. Simultaneously this approach ensures that those generations will have fewer resources and thus fewer real choices to make. Our sociopolitical concerns are actually quite similar to those who argue that redistribution must come first. We differ only in our perception of how to deal with those concerns. Our own choice was to begin by questioning what we view as the basic cause of the growing gap between the rich and the poor - unexamined, uncontrolled physical growth.

V. The Concept of Man

This brings us to the final point that we regard as basic to all discussions among ecologists, "environmentalists", Malthusians, economists, industrialists, pessimists, and optimists. The pro- and anti-growth factions are organized around two very different concepts of man.

One concept of man, the one held by advocates of indefinite growth, is that Homo sapiens is a very special creature whose unique brain gives him not only the capability but the right to exploit for his own short-term purposes all other creatures and all resources the world has to offer. This is an age-old concept of man, one firmly rooted in Judeo-Christian tradition and newly strengthened by stunning technical achievements in the last few centuries.

> Not only ingenuity but, increasingly, understanding; not luck but systematic investigation, are turning the tables on nature, making her subservient to man.[10]

According to this belief man is essentially omnipotent, he can develop at no cost a technology or a social change to overcome any obstacle, and such developme will occur instantly upon the perception of the obstacle. Underlying this view is also the belief that mankind's social, economic, political, and technical institutions operate flexibly and without error, and the best response to any apparent problem is to encourage these institutions to do more of whatever they have done in the past.

The opposite concept of man is also an ancient one, but it is more closely related to the Eastern religions than to the Western ones. It assumes that man is one species with all other species embedded in the intricate web of natural processes that sustains and constrains all forms of life. It acknowledges that man is one of the more successful species, in terms of competitiveness, but that his very success is leading him to destroy and simplify the natural sustaining web, about which he understands very little. Subscribers to this view feel that human institutions are ponderous and short-sighted, adaptive only after very long delays, and likely to attack complex issues with simplistic and self-centered solutions. They would also point out that much of human technology and "progress" has been attained only at the expense of natural beauty, human dignity, and social integrity, and that those who have suffered the greatest loss of these amenities have also had the least benefit from the economic "progress". People who share this concept of man, as we do, would also question strongly whether technology and material growth, which seem to have caused many problems, should be looked to as the sources of solution of these same problems in the futu: Technological optimists invariably label this view of the fallibility of man as "pessimistic"; Malthusians would simply call it "humble".

We see no objective way of resolving these very different views of man and his role in the world. It seems to be possible for either side to look at the same world and find support for its view. Technological optimists see only rising life expectancies, more comfortable lives, the advance of human knowledge, and improved wheat strains. Malthusians see only rising populations, destruction of the land, extinct species, urban deterioration, and increasing gaps between the rich and the poor. They would say that Malthus was correct both in his own time and today in his observation that:

> ...the pressure arising from the difficulty of procuring subsistence is not to be considered as a remote one which will be felt only when the earth refuses to produce any more, but as one which actually exists at present over the greatest part of the globe.[11]

The Challenge

One glaring problem confronts mankind, if it should choose to conceive of man as a humble part of the biosphere. There is essentially no body of knowledge from which to design the new institutions, and values consistent with that concept of man. Two hundred years of growth has left biases and blind spots throughout the physical and social sciences. There is today no economic theory of a technological-based society in which there are essentially zero interest rates, no net accumulation to society's productive capital, and in which the principal concern is equality rather than growth. There is no equilibrium sociology which is concerned with the social aspects of a stable population, whose age composition is skewed toward the elderly. There is no equilibrium political science in which we might look for clues to the ways democratic choice could be exercised when short-term material gain is ruled out as the basis for political success. There is no equilibrium technology that places high emphasis on the recycling of all matter, on the use of the sun's pollution-free energy, and on the minimization of both matter and energy flows. There is no psychology for the steady state which might provide man with a new self-image and with feasible aspirations in a system where material output is constant and in balance with the globe's finite limits.

Each of our traditional disciplines could respond to the challenge of working out the details of a viable and attractive equilibrium society. The effort would pose many difficult technical and conceptual problems, whose solutions would be intellectually satisfying and of enormous social value. After all, we are not merely talking of a distant and unattainable Utopian state. Physical growth of population and capital will stop on this finite planet. The only uncertainties lie in when it will stop and how - by deliberate social choice and under careful human management, or by the harsh backlash of a disturbed and depleted natural environment.

We may all find that the study of a steady-state society may be the best possible preparation for the real future - a future that we are shaping already, with every social and individual decision we make. We will almost certainly discover as we become better acquainted with the possibilities for an equilibrium society that we would prefer the end of physical growth to occur under our own management and sooner, rather than later. Those of us who have already spent several years adjusting to the idea of a no-material-growth society find without exception that we agree with John Stuart Mill, who contemplated the limits to growth more than one-hundred years ago:

> I cannot, therefore, regard the stationary state of capital and wealth with the unaffected aversion so generally manifested towards it by political economists of the old school. I am inclined to believe that it would be, on the whole, a very considerable improvement on our present condition. I confess I am not charmed with the idea of life held out by those who think that the normal state of human beings is that of struggling to get on; that the trampling, crushing, elbowing, and treading on each other's heels, which form the existing type of social life, are the most desirable lot of humankind.... It is scarcely necessary to remark that a stationary condition of capital and population implies no stationary state of human improvement. There would be as much scope as ever for all kinds of mental culture, and moral and social progress; as much room for improving the Art of Living and much more likelihood of its being improved.[12]

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