Sussex Science Policy Research Unit, 1972

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CLW

November 29, 1972

Professor Christopher Freeman
Science Policy Research Unit
The University of Sussex
Nuffield Building
Falmer Brighton BN1 9RF
United Kingdom

Dear Chris:

Because I gave you our preliminary drafts against the expressed wishes of the rest of my group, it is very important for me to be able to portray the forthcoming publication by your group as an ethical and constructive consequence of our agreement. I am finding it a little difficult to do so. Let me describe my impression of our interaction with you over the past year and ask you to fill in any errors of omission or comission.

Last March we published Limits to Growth. That publication was not initially envisioned under the terms of our agreement with the Club of Rome. However, we found in early discussions of our models that most people were unaware of several fundamentally important concepts. Most people do not understand the fantastic power of exponential growth. Neither do they realize that virtually all material aspects of our global social and economic system are exponentially increasing, generally with decreasing doubling times. They do not understand the nature of the long delays in our social systems nor the implications of those delays for the stability of a system which is growing rapidly in an environment which is finite in important ways. Finally, many of them hold simple-minded positive ideas about technology and growth. I need not cite examples. An examination of almost every political and industrial decision with long-term consequences would illustrate my point.

We published Limits for a general audience and without any computer equations because the above issues are clearly unrelated to any single computer model. In fact we seriously discussed at one point completely omitting any reference to the computer model and any use of runs. In retrospect it is clear that the book would have had far less impact had we chosen to omit the computer runs, but it was perfectly possible to express all the basic conclusions of Limits without any reference to the computer. Of course that had been done in the past, for example by Harrison Brown in The Challenge of Man's Future. Incidently, both Forrester and Dana

were in favor of omitting the model until it could be fully described in our technical report.

When it became clear to me that the inclusion of the computer runs was leading many people to accept or reject the ideas presented in Limits for reasons other than their basic merits, I decided it was extremely important to have several other world models available as soon as possible so that there could be some basis for evaluating World3. For that reason I began to look for the three or four groups which I thought had the intellectual and computer resources necessary to provide some alternatives to World2 and World3. Through Kendall I learned of your group, met you and quickly decided that Sussex would be well qualified to carry out related work. I requested a meeting with the SSRC and urged them to support global modeling efforts in Great Britain. I sent you the inconsistent and incomplete first draft of our model description and brought over the second draft in July so that your efforts to develop a model of long-term global problems might benefit from the work we had done. Finally, I invited you to send someone from Sussex to participate in our two week course.

I asked for and received your promise that the material be held in confidence because it was not the final statement of our ideas. Limits went through five drafts. At each point reviewers pointed out technical errors that were irrelevant to the main theses but nevertheless distracting. Through their questions we slowly refined our thinking and focused on a set of central issues. I think one reason Limits has sparked so much discussion is that it has no distracting elements in it. One may agree or disagree with the central thesis but a least that thesis is clear and complete. I confess to having harbored the naive hope that we might receive from your group the kind of comments and questions which would have helped us make the technical report also a clear, concise and complete statement of the ideas incorporated in the model. As you point out in your book, a set of equations is meaningless without information about the mental model that accompanies it. We are trying in the technical report to convey that mental model.

Dana and I did get many questions during our visit with your group in July. However, as I pointed out at the time, neither Dana nor I had done the writing on four of the technical sectors. I had not even had time to go into the details of each model equation when we visited you. For that reason I asked to receive any written material you might prepare on the model so that it could be considered by the people who had actually done the work. I came away from the July meeting with the impression that that material would be sent over when it was available.

We have received nearly one-hundred requests for our technical report. I have given the material only to a few groups. We felt the mental model was not sufficiently well described in the written material for the equations to be of any constructive use except to the groups with which we spent substantial time. It may be worth pointing out that no one at Sussex questioned the ethics of witholding our technical material from the public in July. Quite the contrary, Cournow seemed very pleased to learn that I would not be giving the material to any of the groups competing with you at that time for the SSRC grant. It was also the decision of your group to exclude Burke from our discussions at your laboratory. You mentioned that you would one day be preparing a book analyzing our work. My response was that I welcomed any debate based on our final material. I promised that you would continue to be among the first groups to receive the revised editions of our report. Two months later a friend came back from England with the rumor that the Sussex group was about to publish a book on our model. I didn't even bother to inquire about it because such a book was clearly a violation of the agreement we had made, an agreement which you found eminently satisfactory in July. Since I had not received a single page of analysis from your group, I assumed none existed. I was surprised when I received a copy of Sinclair's speech before the world meeting of Futurists not from Sussex, but from a Dartmouth colleague who had been at the meeting. Then, long after you had personnally committed yourself to prepare a Futurist issue, I got a request to use the "equations" in a few "papers." A few days after that, an American publisher called to announce that he had been offered the rights to a book by your group. When I sent a letter essentially repeating our understanding, I received a letter from you which expressed some new-found distinction between the "equations" of World 3 and the technical report and which threatened "public controversy" if we did not immediately release the material I had provided your group. When I asked you over the phone for a copy of the material, I was told that I could only obtain a copy of it if I signed a blanket release of the equations for your use. If this is the British form of scientific cooperation, then I wish you would start cooperating with Deckerman and Maddox. As a result of my efforts to support the work of your group, I found myself in an extremely unsatisfactory situation with essentially no choice. After agreeing with your demands, I received a roughly three-hundred page manuscript which completely denied any scientific merit to the work which Dana and I and our group have invested two

and a half years. After requesting the privilege of responding to the document I am informed that I may draft a reply, but that my response will have to be sent off to the publisher in less than a week. You asked for permission to publish the equations of our model. You are also using text and figures - some of which no longer are present in the third draft. You are releasing a one-sided review on the basis of privileged information to which few others in the scientific community have had access. How can any reader realistically put your comments into context? By withholding from us the same privilege I extended to you, the opportunity to look at early drafts of your work. You have managed the affair so as to block any scientific debate of your position. I don't think it is useful to speculate about the actual motives involved, but I wish you could summarize them for me briefly.

I recognize that about 60 percent of your material deals with issues that transcend our technical report. The discussion of the interaction of mental with computer models is quite good. I wish you were somewhat less willing to imply our complete ignorance of that interaction, (I have enclosed a recent paper in which I describe the interaction and the questions it poses for modelers and for policy makers), but that part of the manuscript is a useful contribution to the discussion. World2 is open game, of course, as are the basic ideas in Limits. But to criticize in detail our assumptions when we have presented them to you in an incomplete fashion and when no one else will be able to examine our defense of them is difficult for me to understand.

Though I personally attribute much of the problem to lack of communication, not lack of good will, I think the use you have made of our technical material is a gross violation of ethics. I know that you did not set out last spring to use the special arrangement I offered for personal gain, but the consequences of the violation are no less serious. I think it is inappropirate to publish the five chapters criticizing the global model. I think you should wait to revise them in response to the last draft of our work and release them simultaneously with our book. Since you asked for permission only to publish the equations of our model, I have sufficient ground to block you from releasing anything which employs quotes or figures from our report. That is a technicality to which I will not resort.

Worse than the ignorance of the mutual responsibility involved in our agreement is that fact that your release of the material in its current form and at this time will force the debate to a level and a mode which is likely to obfuscate the realiissues involved in our model. I wish you could have given us the opportunity to comment on an early draft of your work. You have dwelt on trivial issues, some of which you have completely misunderstood and all of which are irrelevant to the points that you or I really want to make. Your discussion of these issues

will certainly distract debate from the central ideas. For me to provide you with preliminary drafts of our work for your personal use and for you to provide me with final drafts of your critical analysis through an issue of Futures strikes me as a little asymetric. It also forces me to a move I very much regret. I now have little alternative except to express in public criticisms which I would have much preferred to convey in private. While there is not time to prepare a comprehensive discussion of your remarks - several points will have to be made. I find much to admire in your work - but you have entirely missed the point in some cases. Moreover, the way in which you have expressed your criticisms will lead most of readers to a false impression of your views.

There will be tendency by your group to disregard this entire letter as the product of someone who does not like being criticized. Please note that I have never questioned your right to disagree with our conclusions nor with your right to publish your disagreement as soon as you have the final draft of our report. Neither am I under the illusion that an editorial revision of our work will eliminate your concerns. If I had wanted to ensure that several patronizing reviews of our work appeared at the same time as the technical report, I could easily have arranged that. As it is, theppeople eager to compliment our work are still waiting for a copy of the technical report. Instead I worked hard to arrange so that our technical statements about global models would not exist in isolation. It is your group which appears very anxious to avoid criticism.

I make it a point to clearly inform any of my associates when they have done something which I consider unethical. That is an important objective of this letter. You may accept or reject my criticism, but at least our future relationship will not be marred by misconception of my group's feelings. Another objective of this letter is to suggest that you reexamine the rules that guide you in your cooperation with other groups. If policy-oriented modeling is to transcend the level of nationally-oriented justifications for preconceived ideas, it is essential that groups work together across national boundaries. The standards you have so far set for your cooperation with my group will not long secure you the forthright exchange of information and ideas with groups outside Sussex which your work also requires.

Though I will be a little more careful to outline the exact details of future understandings, I don't intend to let any of the above interfere with future cooperation with Sussex. I still consider your group to be one of the two or three best in the world in its potential contribution to long-term social analysis. I am working now to minimize the disturbance caused by the misunderstanding and to respond as constructively as possible to your actions.

By laying waste to two months of personal commitments, I have been able to move our planned publication date up by four months so that the technical report should be available from the publisher in mid-April. The resulting document will be a far less carefully worded description of our work than I had planned, but thatappears the lesser of two evils. I hope I can distribute several dozen copies of the technical chapters in early January to other groups. A year from now when the initial flurry has blown over, the major cost of your inexplicable haste will be the loss of a unique opportunity. If our two groups had worked together to refine the two books into expositions of the principle areas of disagreement, they would have served for a long time as important references to this preliminary period of social model building. Under the circumstances, I suspect they will be quickly superseded. Certainly both manuscripts in their current forms bear the signs of hasty and inconsistent preparation.

Now that I have told you how my group feels about this, we can get back to the important job of our technical work. If I can only get you and your associates to define cooperation as a two way flow of information, our work will benefit from your ideas and comments. I do look forward with real anticipation to the meeting in Copenhagen this summer. I hope one of your colleagues can come join the fray. I even intend to invite Beckerman once the donference funding is assured.

Cordially,

Dennis Meadows

DM:c

THE UNIVERSITY OF SUSSEX
SCIENCE POLICY RESEARCH UNIT
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Telephone:
BRIGHTON (0273) 686758

10th November, 1972.

Professor D. Meadows,
The Thayer School of Engineering,
Dartmouth College,
Hanover,
New Hampshire 03755,
U.S.A.

Dear Dennis,

I think that you may have mis-understood our request for release of the Technical Report. Our papers submitted to Futures and for later publication by the Sussex University Press are a critique of World Dynamics and Limits to Growth. Our request relates only to the basic assumptions and equations in the World 3 model. These must be the same in all versions of the Technical Report and in Limits to Growth, as I am sure you would not change them after publishing your conclusions based on World 3 in Limits. Indeed from this standpoint, apart from any typographical errors, the early versions of the Technical Report are more relevant than the new draft which you will have in mid-November. We did not anticipate that our request would cause you any problems, which is the reason I wrote in the way that I did: ("Unless we hear from you to the contrary.." etc.). I thought that this was simply a formality prior to circulation of our draft and subsequent publication.

We would of course be very interested in your new draft of the Technical Report and particularly in the new chapters. We would be glad to comment on them to you privately and, after you publish them, in the public literature. But this point should not be confused with our request for your consent to release the model equations and assumptions in the Technical Report for open comment. We understand that you intend to achieve two purposes with your revision of the Technical Report:

(i) to make available the necessary technical data for normal scientific debate on World 3;

(ii) to produce a new book with much new commentary and additional analysis.

We are concerned at the moment only with (i). Forrester published his equations with his book, which of course is the normal scientific practice and it would in our view have been better if you too had published a 'technical appendix' to Limits in the same way. However, we appreciate that there may have been practical difficulties in the way of this. All the same, as I am sure you are well aware, the

continued delay in release of this technical data is damaging to the reputation of your group, particularly after Carroll Wilson's explicit public statement in Science (23 June 1972) that the report would be released in June. Consequently we really do believe that it would be in your own best interests, as well as in ours, to release the report not later than the end of this month. If you would prefer us to make reference to the final version we will do so, provided we receive it before the end of the month, or if you would prefer it, we will not make any specific references to pages or chapters of the Technical Report, but simply discuss the assumptions.

It is possible that there are issues affecting the Club of Rome which are making you hesitate about the release. In case this is so, we could if you wish immediately send copies of this letter to Dr. Peccei, Dr. King, and Dr. Thiemann, and to our own Vice-Chancellor, who is a member of the Club. I am quite sure that they will agree with us that everyone's best interest will be served by permitting us and any other groups concerned to comment on the basic assumptions of the World 3 model. We would very much prefer to settle this question without any public controversy. Please do not force us to make an issue of this. We would have to do so if we did not receive your clearance in November.

I convinced Freeman this was on file 4 us free

We have now received a contract from the SRC and SSRC to do further work on world models in 1973. I am sure that you will have plenty of opportunity in the future to make your own thorough criticisms of our efforts, and we shall welcome your public criticism, as well as private.

We have acted throughout in the belief that both your group and the Club of Rome were completely sincere in your statements that you wished for a well-informed professional public debate around World 3, even if this involved some strong criticism of the assumptions of the model and your conclusions. You will see in the enclosed draft of our "Acknowledgements" that we pay tribute to you on this very point. Hence our request is simply the standard norm of scientific debate that when important new results are published in any branch of science, qualified researchers should have the opportunity to analyse the experiments and the data critically, and to publish their results too. In view of the first paragraph of your letter I am sure that you will accept this.

We have never hidden from you that we had many deep disagreements and criticisms over World 3. Indeed you spent a day patiently listening to a barrage of comment, criticism and interrogation in July. As you know, many of these criticisms are so fundamental that they would require

Continued.....

a new model, rather than a new version of the Technical Report, to accommodate them. However, since you specifically request it, I enclose a summary of about twenty of our major criticisms of the World 3 assumptions and structure. We will of course send you the full set of papers as soon as we get your clearance.

I very much hope that as in our July discussions, despite our deep and fundamental disagreement on many of the issues, it will be possible to conduct this debate, both in private and in public, in good faith and to preserve good personal relations between our groups. I realise that this may be difficult, but we would certainly like to keep it that way. For this reason, I welcome your invitation to the Copenhagen meeting, which Dr. Cole or Mr. Curnow will take up. I would like to take the opportunity to thank you again for making available the earlier versions of the 'Technical Report' and for your July visit. Despite any disagreements, you and Dana are welcome in Sussex any time, and I would be very glad to meet you when you are in England.

Yours sincerely,

Chris

Professor C. Freeman

I called Chris Nov. 15 to learn their precise plans.

My cable Nov. 16 read:

I confirm release of technical material for use in February Futures and book released March 31. Please send review Meadows at Dartmouth and Forrester at M.I.T.

MEADOWS

A RESPONSE TO SUSSEX

Donella H. Meadows
Dennis L. Meadows
Jorgen Randers
William W. Behrens III

December 10, 1972

A RESPONSE TO SUSSEX:

Malthus has been buried again. (This is the 174th year in which that redoubtable economists has been interred. We may take it as certain that anyone who has to be buried 174 times cannot be wholly dead.)

-Garrett Hardin,
Bulletin of Atomic Scientists, November 1972, p. 23.

Introduction and Overview

The MIT System Dynamics Group has developed an explicit theory of the long-term global interactions between population and the economic system. We have analyzed that theory, or model, to learn something about the long-term causes and consequences of growth in population and material output in a finite environment. We have concluded that important social and technological changes are required to avoid undesirable consequences of approaching physical limits, changes toward a global state of demographic and material equilibrium.

The members of the Sussex Science Policy Research Unit believe, on the contrary, that there are no foreseeable physical limits to population growth and that attempts to slow physical growth may themselves have disastrous results. The Sussex group believes that current institutions and values are fully capable of guiding demographic and material growth in directions that will satisfy man's needs.

Our own theory of growth has been made explicit so that others might examine its component relationships and analyze its implications. The Sussex authors have not put forward an alternate theory of growth to support their views, nor have they described in precise terms the processes of social change and technological advance that they believe will accommodate current growth processes. However, from their analysis of our work it is possible to infer many attributes of their views. In this response we will describe and analyze five major areas of disagreement between the two groups:

I. The Sussex authors imply that present short-term, reductionist, predictive models are appropriate for addressing the causes and consequences of population and material growth. We

believe that a new type of model is required, one that can be based on the imperfect data and theories that are now available This sort of model is an attempt not to predict the future but to illustrate the basic dynamic tendencies of a complex system under alternate policies. We will show that the Sussex authors' unfamiliarity with this new type of model has lead them to make numerous technical mistakes and to misinterpret our models and conclusions.

II. The Sussex group confuses the numerical properties of our preliminary World models with the basic dynamic attributes of the world system described in The Limits to Growth[1]. We suggest that exponential growth, physical limits, long adaptive delays, and inherent instability are obvious, general attributes of the present global system. They warrant urgent concern and study, whether or not the precise assumptions of our particular computer models are ultimately accepted. In its preoccupation with the characteristics of particular models, the Sussex group has ignored some of these general attributes and misinterpreted others. Their work has not disproved or contributed to man's understanding of any of these dynamic properties of the world system.

III. The Sussex group postulates price, technology, and values as stabilizing mechanisms in the world system. We view each of these three mechanisms as subject to the same delays, short-term perspectives, and tendencies toward suboptimization that we have postulated as the basic causes of the global system's inherent instability. Because Sussex has provided no explicit or complete description of the social, economic, and technological change they envision, it is difficult to evaluate the basis for their optimism.

IV. The Sussex team implicitly assumes that only perfect and objective models can be the basis for social policy, and that all important long-term decisions can wait until these models are available. We would suggest decisions being made today

already determine social costs and benefits for twenty, fifty, or more years into the future. Those decisions are already based on some long-term view of society. Instead of waiting for perfect models, we must work to construct and implement the best models possible today. The Sussex authors suggest correctly that our own models are influenced by the social milieu and the subjective impressions of our group. They seem unaware that every basis for a decision, whether intuition or computer model, bears the stamp of its maker and his environment. The Sussex group does not recognize or define the biases behind its own position.

V. The most important difference between the two groups is the underlying perception of man's place in the global system. Sussex believes that man can and should master nature for his own short-term needs. We suggest that man's tenure on earth will be longer if he can learn to formulate his goals and manage his affairs so that short-term solutions do not decrease long-term options.

Unfortunately there is no objective way to resolve the basic disagreement between the two groups. However, it is critically important for human society to determine which concept of man is a more appropriate basis for current policy.

Historical Summary

With the publication of World Dynamics,[2] 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 analysis 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 to be 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, the MIT System Dynamics Group has prepared four documents on the dynamic implications of physical growth in the global system. The first published technical document, World Dynamics, 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.)

In our second publication, The 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. 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 discussed the history and the implications of our project and that described 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. This technical report presents the assumptions, equations, and data underlying World3 and analyzes the model's behavior under alternative assumptions. The technical report will be published in the spring of 1973.[4]

In June, 1972, we presented preliminary and incomplete drafts of our technical documents to several working groups around the world, so that they could undertake their own modeling efforts with at least a rough knowledge of the reasoning, resources, and methods we have found useful. We encouraged critical analysis of our basic postulates and technical work, but requested that specific comments be released only when the particular technical document to which they related became available to the general community. Because of our respect for the work of the Science Policy Research Unit at Sussex University, we offered the Sussex group full access to our preliminary reports. Inexplicably, the Sussex group has chosen to release its criticism before the last technical document becomes available to the scientific community. In addition, the Sussex manuscript was withheld from our group until only a few days before the publication deadline for Futures. As a consequence, it is impossible for the reader to assess independently the relevance and accuracy of the Sussex comments on our technical report, and impossible for us to respond to these comments in full detail. We refer the reader to our technical report, where the World3 equations and the reasoning behind them are described fully. In these few pages we will attempt briefly to clarify the principle areas of disagreement, to point out the more important assumptions implicit in the Sussex work and to evaluate the conclusions it offers.

Although many of our statements here will be critical, we should emphasize that the Sussex work contains several important contributions. When the Sussex group is on familiar ground---

especially economics and the history of forecasting---its work is authoritative, and its comments on our own work are generally correct and useful. When the group ventures into new fields---particularly into system dynamics, ecology, and control theory---it makes some serious mistakes.

In discussing those mistakes here we do not mean to imply that we resent the trespass of the Sussex group into the field of system dynamics. That a group of social and physical scientists has seriously tried to understand and use system dynamics demonstrates the openmindedness and interdisciplinary concern of the group members. That they have made errors in their first attempt is not surprising, nor should it be discouraging. It seems to us that if research groups do not continue to try in this way to see beyond the boundaries of their own limited disciplinary turfs, they will add little to our understanding of complex, single-system world in which we live. We hope that the readers of this exchange will be able to distinguish the chaff from the grain in both contributions.

I. Technical Errors in the Sussex Analysis

The training and professional expertise of the Sussex group is predominantly in economics and the physical sciences. Both of these fields have evolved a modeling philosophy that is primarily directed toward precise, short-term prediction. Because economic and physical models are based on principles and theories developed over many years, training and experience are prerequisites for the effective design, analysis, and evaluation of these models.

System dynamics models are general and holistic. They are designed not for short-term predictions, but for exploration of the long-term dynamic properties of complex systems. A minimum level of training and experience in feedback systems and control theory is a prerequisite for the construction and analysis of

system dynamics models. Without that training, it is possible to make elementary mistakes and to expend unnecessary energy analyzing irrelevant issues.

The brief list that follows illustrates some of the errors the Sussex group has made in their analysis of the World models. The following discussion should not disguise our appreciation for their attempt at thorough and systematic analysis of the World models. Nor should it imply that we reject all of their criticisms. If anything the following comments simply confirm the Sussex view that one's predispositions and intellectual habits have a profound influence on his use and interpretation of formal models.

The most fundamental error of the Sussex group is in its choice of perfection as the standard used in evaluating the World models. In each of our publications we assert that the models are not offered as perfect theories of demographic and capital growth. We suggest that our theories appear to be more comprehensive and more objective than the mental models of long term population and economic processes which currently guide the formulation of social policy. No current theory of social processes is correct. No future theory of social processes will ever be fully correct. The Sussex group addressed fourteen chapters to a point we readily acknowledged in each of our books: the World models are <u>not</u> perfect. However, by choosing to attack the straw man of perfection, the Sussex group has decreased the difficulty and the significance of its effort in two ways. First, the group members could concentrate on the individual (and relatively unimportant) numerical assumptions of the models rather than on the underlying causal relationships that constitute the real substance of our work. Second, the group relieved itself of the burden of providing superior alternatives.

The Sussex critics point to the unsatisfactory nature of the data underlying the World models. They do not point out where better information can be found; in fact they generally admit that it cannot be found. They point to assumptions in the model that are imperfect; they seldom suggest how more perfect alternatives might be developed (their section on the World3 capital sector is an exceptio.). They disagree with the conclusions we have derived from our models, but they do not put forward an alternative model in which they have more confidence. They complain that system dynamics is not a perfect methodology, but they do not suggest a better one.

Were they perfectly content with the world as it is, their criticisms of our models would be easy enough to understand. However, they seem to share our concern over the potential implications of current global trends. Their review is a systematic and, in many cases, accurate identification of areas in which the World models might be improved. If their exercise had led them to construct an alternative model, free from the imperfections they perceive in our work, their study would have been a fruitful exercise. Without that alternative model, however, their review is simply an argument for the status quo. While we agree with Sussex that "our attempts to model complex systems are still at a very primitive level" we would compare that primitive level not with an unattainable perfection but with the models that now shape social policy.

A second mistaken Sussex assumption is that the validity of models is indicated by their ability to reproduce historic behavior, when run either forward or backward in time. "Back-casting", or running the model backward, is a technique proposed by Sussex to test the ability of the World models to "predict" real-world data from time periods prior to their initialization point. Employing this criterion,
Sussex attaches great importance to the inability of World2 to reproduce real-world behavior when the sign of its solution time increment is made negative, so that its simulation proceeds backwards in time from the year 1900. "The [World2] curves are curious - they seem to indicate that the twentieth century lies in the aftermath of a catastrophic population collapse (from a previously infinite population) dated about 1880."

Implicit in Sussex' test is the curious assumption that the real world would retrace its own path if it were to be run backwards. No justification is offered for this view. Any scientist trained in the theory of control systems would understand that reversing the sign of the solution time increment to make a feedback model "run backwards" must radically alter the entire dynamic character of the model. With a negative time increment, negative loops are converted to positive ones (for

example population will be augmented by deaths and depleted by births). Model elements exhibit completely spurious excursions. The discovery of one such excursion in the World2 population (Figure 1A) is cited by Sussex as an imperfection of the model. In fact, the World2 population will also explode under reverse simulation from many different starting points. For example, as Figure 1B indicates, if the model is initialized in 1940, and run backwards, population explodes by the year 1920. Since World2 does not even backcast its own behavior, the Sussex criterion would force us to conclude that World2 is not a good model of World2.

Running a system dynamics model backwards tells us nothing about the model's utility in understanding the world. The meaning Sussex automatically assigns to backcasting illustrates the influence on their work of analytical habits gained in the context of substantially different kinds of models. Their failure to understand the causes of the "population explosion" reveals an ignorance of simple control theory. The Sussex authors suggest it is important "to examine the great catastrophe of 1880" in World2. We would suggest it is more important for them first to understand the mathematical properties of multiloop feedback models.

A third error is the assumption that one model can be made to serve many different purposes. System dynamicists recognize that the elements of a useful model must be carefully chosen to illustrate some closely related set of issues. Thus a hierarchy of models is often necessary to deal with different dynamic aspects of a system. A long-term aggregated model can be constructed to identify the basic behavioral tendencies of the system. This is the purpose of the world models. In working with the aggregated model one typically identifies critical sub-problems and important areas of insufficient knowledge. Then shorter-term submodels may be constructed to evaluate specific policy alternatives, to clarify

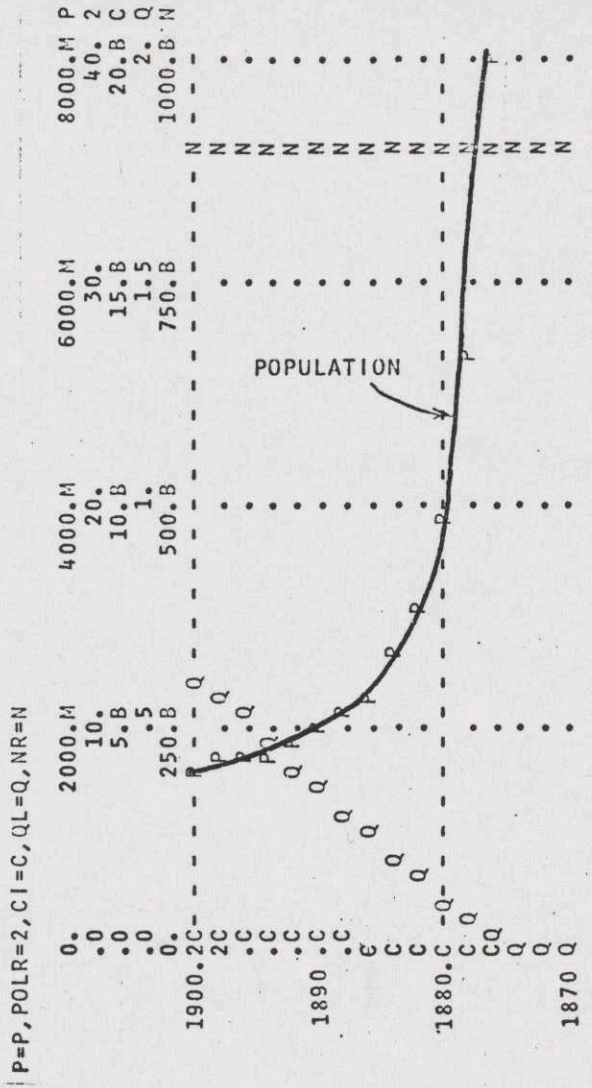

Figure1A: World2 run backwards from 1900

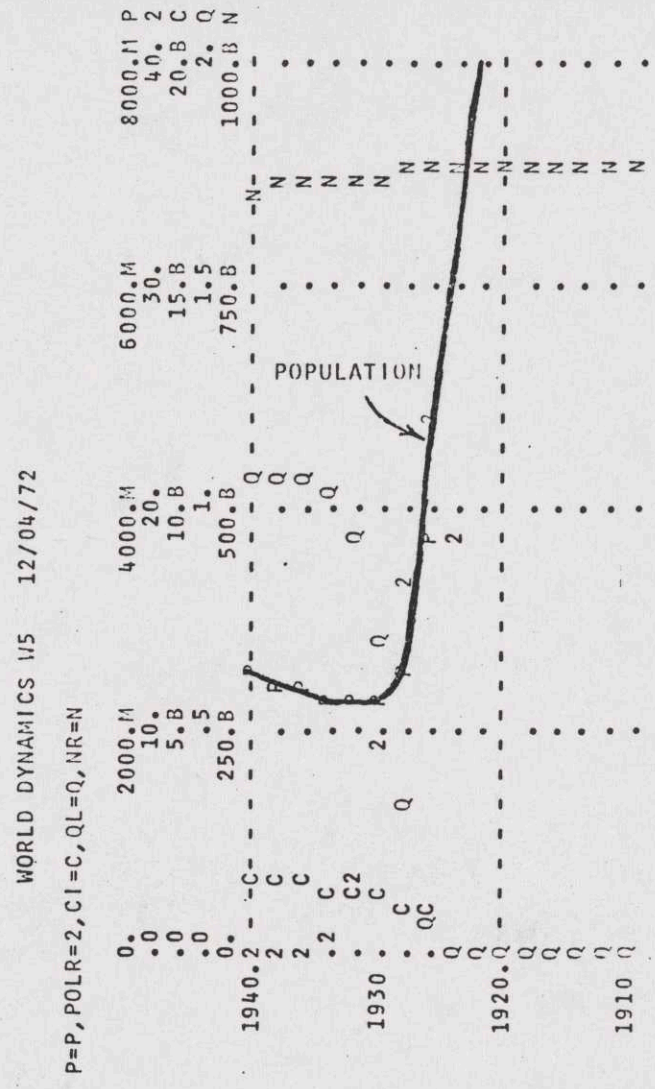

Figure1B: World2 run backwards from 1940

Figure 1: These two figures demonstrate that running the World models backward does not provide any valid information on the model's utility in understanding real world processes. Figure 1A illustrates the behavior obtained by the Sussex group in running Forrester's world model backward in time from 1900. Because population "explodes" in roughly 1880, the Sussex group concludes that the model is a poor representation of reality. However, Figure 1B shows that a similar explosion occurs, this time around 1920, when Forrester's model is run backward in time from 1940. This explosion occurs although Forrester's model exhibits perfectly reasonable behavior when run forward through this time period. Conclusions based on runs of the model backward are thus irrelevant in assessing the utility of the model in the standard forward simulation mode.

areas of uncertainty,and to test the appropriateness of the simplifying assumptions made in the more aggregated model.

Our group constructed numerous sub-models during our research on the global models. These sub-models explore issues such as the determinants of recycling, the influence of technological advance on resource availability, the effect of price increases on stimulating new resource discoveries, and the dynamic character of the transportation and concentration of persistent materials through the global environment. There is no acknowledgement in the Sussex review of this work, even though it constituted about fifty percent of our project and provided information on many of the relationships that are reported to be missing from the World models. For example, the report on the pollution sector of World3 criticizes our assumption about the transmission delay exhibited by persistent materials without referring to the models of DDT and mercury diffusion specifically constructed to examine that parameter.

Another mistake that appears frequently throughout the review is the error of representing a new policy by changing one parameter without recognizing that other parameters must change simultaneously. Sussex states "in the World3 model, it is important to note that the effect of increased expenditure on anti-pollution equipment is to raise the capital use and so to increase pollution". This statement ignores the role of the analyst's mental models in altering the model and assessing the results. Were anyone from our group to test the effects of increased investment in pollution abatement capital, he would simultaneously decrease the coefficient in the model that expresses the emissions associated with the average unit of capital. The result may or may not be increased capital and decreased pollution emissions, depending on the assumed effectiveness of the pollution abatement. After all, it is true of the real world that some pollution is generated in the manufacture of anti-pollution devices.

The Sussex group seems to misunderstand completely the role of initial values and time in the World models. "But if he [Forrester] had started his model run at 1880 with initial values based on his arguments in World Dynamics the collapse predicted by the standard run model would be brought forward by 20 years. And if he started the model at 1850 the collapse would be predicted for around 1970", (Sussex Chapter 9). Because the numerical value of time is often employed as a causal factor in econometric models, Sussex has apparently become confused by its simple role as an indicator of lapsed chronological interval in system dynamics models. Every system dynamics model incorporates a set of initial values for the level variables that are self-consistent and characteristic of some point in time (1900 for the World models). The model is simulated to trace the effects of the initial values and the causal interrelationships over time. Had we wished to start our simulations in 1850 we would automatically have selected a set of initial values for population, arable land, etc., characteristic of 1850. With these new initial values the collapse would not have come in 1970, but at about the same time as it does in the current model.

Another technical comment will illustrate the Sussex confusion about the relation between the level of available information and the complexity of a model. Sussex criticizes the World3 pollution sector for being too simple - "the modeling of the pollution sector in The Limits to Growth has achieved...a final simplicity by ignoring all complexity". We made our short-term models of specific pollutants highly detailed, for much is known about the behavior of DDT and mercury. But little can be said with confidence about the long-term behavior of a class of materials whose members have in many cases not yet been identified. Our pollution assumptions, listed at the beginning of Sussex Chapter 7 were all we felt could be said with confidence about an important class of pollutants, persistent materials. We have not ignored all

complexity, we have simply found nothing more in the current understanding of the dynamics of the ecosystem that appeared to be relevant to the physical determinants of the behavior of persistent pollutants over the next century. In time ecologists will learn enough to make much more detailed statements about the behavior and influence of pollutants in the global system over the next century.

Another characteristic of the Sussex comments is the tendency to deny our assumptions for lack of sufficient data and then to postulate an alternative set which is just as poorly based. The natural resource sector analysis provides an excellent illustration of this tactic. In Chapter 3 the Sussex group states - "There are two components to this question: what is in the earth (and where); and how much of it will prove exploitable over the period of concern? The present state of knowledge is such that neither question can be answered in detail and with certainty." From that basis the Sussex group goes on to state in detail and with certainty that the M.I.T. estimates are too conservative.

The Sussex criticisms apply micro reasoning to macro problems. In both the resource and pollution sectors Sussex tends to dwell on carefully selected positive local evidence, while ignoring both the evidence for and the causes of negative global trends. The Sussex authors point to cleaner air over London or the reduced amount of a specific resource used in some particular application. On a global scale, however, they ignore the facts that the consumption of virgin resources is increasing by a factor of two about every fifteen years and that the global rate at which extracted materials are dumped into the environment is increasing at about 5 percent per year.[5] The enormous quantities to which this rate of increase can lead have been illustrated in The Limits to Growth. It is true that this physical mobilization of materials need not increase at that rate indefinitely, but Sussex never seems to explain why it is doing so at present, or what will cause it to slow down.

We could point out numerous other examples of misreadings, misunderstandings and misrepresentations of our particular model or of system dynamics in general. They are trivial points compared to the major areas of disagreement, and therefore we will leave them for readers of both technical reports to discover for themselves. Some of them may well be due to the fact that in its haste to publish Sussex worked with an early draft of our manuscript and did not ask us for clarification of unclear passages. These small mistakes indicate only that the technical comments of the Sussex group are not made from a very strong basis of understanding or of expertise in working with dynamic models. These mistakes can easily be corrected and would thus be relatively unimportant, if Sussex had not implied that criticisms of the detailed equations of our models are somehow equivalent to disproving the fundamental dynamic properties of the global system described in The Limits to Growth. Therefore it becomes necessary that we restate and discuss those fundamental properties.

II. 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 attention to these basic dynamic properties, rather than the model equations, that we presented them to a nontechnical audience in a publication separate from the technical model description. We shall summarize here the main points from Limits and discuss the Sussex response to them.

1. Exponential growth is an inherent property of the population and capital systems. Population and material capital grow exponentially by the very nature of the reproductive and productive processes. This is not an arbitrary assumption or an "elegant mathematical invention" (Sussex Chapter 14), it is a

fact amply demonstrated both by empirical evidence and by knowledge of underlying causes. New people can only be produced by other people, and machines and factories are needed to generate other machines and factories. 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 growth, varies, both in the real world and in the World models. The growth process is, nevertheless, inherently exponential.

It may be true, as the Sussex group points out, that human knowledge, also by its very nature, grows exponentially; knowledge can lead to the accumulation of more knowledge. It does not follow that any given technological application of that knowledge is inherently exponential. Discovery of oil is not in the long run made easier by the fact that certain 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. To suggest that these "exponential" technologies are inevitable and to include them in a formal model, as the Sussex group did, demonstrates a profound misunderstanding of the inherent cause of exponential growth. It also implies a rather sweeping disregard for the second law of thermodynamics and the law of diminishing returns.

The Sussex group then compounds this error by claiming that the introduction of exponential technologies, which change the model behavior, proves that the model is "sensitive" to its assumptions.[6] The model is indeed sensitive to the fact that limits have been postulated for the system; if the limits are removed the system can grow forever. This statement implies nothing about the mathematical or parametric sensitivity of the model. It only illustrates the obvious fact that if one assumes the world is infinite or growing faster than population and capital, there is no ultimate limit to physical growth. Sussex did not need to alter and simulate our model to make this point.

2. There are physical limits to population and capital growth. As we have already indicated, the World models are built upon the assumption that the earth is finite, and that some change in current exponential growth processes will thus be necessary to accommodate 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. Professor Freeman is correct in categorizing the models as "Malthus in, Malthus out". The inherent advantage of computer models over intuition is that their conclusions are always a logical consequence of their assumptions. We chose to investigate a Malthusian view of a limited world because, as the Sussex group again correctly points out, our own impressions 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 limitation. We are indeed Malthusians, at least in a broad, total-system sense.

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. We know that to some 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 conversations about superseding one limit are meaningless without

considering the system as a whole. The Sussex analysis amply illustrates how easily any single resource, food, pollution, or population problem can be mentally "solved" by assuming that sufficient 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 bias as modelers and our perception of exponential growth indicate 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 prone 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, dumps of wasted resources, depleted ore bodies, simplified ecosystems, and deprivation of other humans in other cultures 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 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. The Sussex group has correctly suggested another omission - social limits. 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. Perhaps we phrased the distinction between these two kinds of limits too strongly. They are closely related, in ways man is only beginning to understand.

As a simple example, America was a land of equality for more than 100 years, while her resources were abundant and unexploited. Almost any citizen desiring it was given 125 acres of good farming land. No difficult trade-offs had to be recognized between one set of social interests and another; there were resources to satisfy all. This is not to say there were no social problems. There were simply no social problems limiting physical growth. In fact growth was the favored solution to social problems. The accumulated effects of past growth have ended that situation. Land distribution in America is becoming more inequitable as population and industrial growth cause land prices to rise. The trade-offs that were once resolved by growth now must be resolved by social institutions that are, so far, unequal to the task.[7]

3. There are long delays in the feedback processes that control the physical growth of the world system. This is probably the most important point of the World models. Delays are the main source of instability in the model systems. 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, as the Sussex group implies, 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 environment.

The combination of three assumptions causes the "overshoot mode" of the models: The assumption of feedback delays, the assumption of possible erosion of the earth's carrying capacity, and the assumption that the value system of man's society will favor population and material growth until incontrovertible evidence is available that such growth cannot continue. When, in the "equilibrium" mode, we assume a change in that value system, the overshoot no longer occurs. The overshoot could also be eliminated, or minimized, by assuming that the society can do accurate long-term planning, eliminating or allowing for many feedback delays. Of course our purpose in publishing Limits was to encourage both the value-change and the long-term planning processes.

The Sussex group has suggested that there exist numerous undelayed feedback mechanisms that do allow society to respond adequately to a changing physical or economic environment. They have suggested three possible adjustment mechanisms; the economic price system, technical change, and change in human values. Later in this paper we shall discuss our own mental models of these three mechanisms. The Sussex group has a responsibility to do the same; to define their perceptions of these economic, technical, and social forces in terms of their exact causes, their probable magnitudes, their inherent time delays, their real costs, and their probable impact on all parts of the system.

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 that cause 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.

The Sussex report as a whole seems intended to assure social institutions that any signals of impending limits must be spurious. It states that there is no foreseeable resource problem, and no limit to food production, and that pollution is just about to be cleaned up. On the other hand the group seems to feel that population growth, some forms of environmental deterioration, and some forms of material growth are serious threats, to which they fully expect social or technological response. It is difficult to reconcile their confidence in that response with their energetic attempt to deny the signals that might generate it.

As we stated in Limits, we have no desire to stop the development of technology. Combined with the necessary value changes that

will control physical growth, new technologies can create magnificient possibilities 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. The equilibrium state may be a desirable option, wherever the limits to growth may be. 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, pollution-creating resources. Limits ends with a rather Utopian description of such a state. We sincerely believe that some form of 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 such 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 may 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 present maldistribution of resources or income. We have already suggested in Limits that we would expect just the reverse. We would hope that more imaginative responses will come to the challenge of thinking through the economics of a physically stabilized state.[8] We suspect that the exercise would be more than theoretical; that it would illuminate some of the current economic 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, although many, including the Sussex group, have attributed such suggestions to us. 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, the basic points of our modeling effort, as described in Limits, have been misunderstood or distorted by the Sussex group, or ignored by them in their attention to nonessential details of the World models. It seems to us that all of these points still 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 not inconsistent 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.

III. Price, Technology, and Values

Now let us return to the three mechanisms that the Sussex group believe will allow mankind to sustain and control material growth. All three are actually included in the World models, but in implicit and oversimplified form. Because all three are important, complex, dynamic sub-systems in themselves, we will describe here, very briefly, how more complete representations of these sub-systems might fit into and alter the World models.

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. Sussex postulates 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 behavior of these submodels was unstable in the same way that the resource sector of the World models is unstable.

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 may 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 reasearch.
- -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 total impact of the technology on the system, including social, energy, and environmental costs.

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 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 have 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 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 maximize 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 realtionships 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, 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 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 advantage 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 socioeconomic system might be thought of as a constant interplay of human desires and goals with 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 areinfluenced by the process 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 system 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 industrializing population.

Human values, like human technologies, may evolve in the future in directions we cannot possibly foresee at this moment in history.

Therefore 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. Therefore we have also included, in several model relationships, test switches that can be used to activate postulated value changes at any data specified by the operator. (Example 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.)

IV. The Modeler and his Environment

On one point we concur fully with the Sussex report. Computer models must be evaluated as part of the cultural context within which they are constructed. This relation between computer and mental models exists because every model of a social system must omit some details of the real world. Simplification is the essence of model building. A model is constructed to improve understanding of the nature and implications of complex relationships in the real world. If the model were identical to the real world in all respects, 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 Sussex report implies that the social milieu somehow has unduly influenced the World models, but that the Sussex assessment is reasoned and objective. Of course every premise that serves as the basis for human decision is a model and is influenced by personal and social values. The outstanding attribute of computer 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. The Sussex group has not defined the bias that underlies their own approach, nor have they presented assumptions explicit enough to be judged by their audience.

A second implication of the Sussex discussion, particularly Chapter 12, is that since society's prevailing attitudes influence models, the models must be addressing random, unimportant, or spurious issues.

There has been an enormous increase in concern for the environment among the western industrialized nations. The latest wave of environmentalism may turn out to be a fad, merely the result of rising expectations, as Sussex suggests. It

may also be a result of the first glimmerings of human understanding about total systems and the first human perception of the worldwide negative impact of man's activities on the ecosystem. There certainly is less horse manure in London today than there was in 1900, but the industrial and agricultural activities of man are pouring into the environment today materials in varieties and quantities that dwarf by orders of magnitude the effluents associated with any horse in a previous age.

It may be worth at least considering the possibility that the environment that led to the World models is a truly changed and threatened environment. If so, the World models may be a small example of the very adaptive social mechanisms in which the Sussex group believes so firmly. Certainly the pro-growth reaction of the Sussex group, among many others, is an example of the social delays and inflexibility in which our own group believes so firmly.

V. The Concept of Man

Professor Freeman in his introduction lists three basic points of difference that he perceives between his own group and the group that has worked on the World models. We would like to conclude by commenting on each of these points of difference and then by discussing what we feel is an even more basic difference that has shaped the philosophy, models, and behavior of each group.

First, Professor Freeman states that he rejects 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 in 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 insures that those generations will have fewer real choices to make. Our sociopolitical concerns are actually quite similar to those of the Sussex group. We differ only in our perception of how to deal with those concerns. Our own choice was to begin by questtioning what we view as the basic cause of the entire set of problems - unexamined, uncontrolled physical growth.

Freeman's second point concerns the relative reliance of the two groups on the beneficial effects of technical progress. We have already outlined our model of the effects of technology on the world system. We cannot view it, as the Sussex group consistently does, as a cost-free, purely-beneficial, miraculous force that can repeal natural laws and roll back physical limits indefinitely. We do not believe that even the most enlightened social assessment can create that kind of technical progress.

It is a testimony to the strength of Freeman's entirely different belief that he is not even able to comprehend our position---he believes that the World models collapse because we have assumed that sometime in the future technical progress will fail. When the World models collapse, they do so because of the accumulated costs and side-effects of technical successes, each operating in a separate sector of the model, attempting to maximize output of that individual sector by drawing resources from other sectors. As we have stated in Limits, some kinds of technologies are essential to the equilibrium state, and we would welcome them. We do not believe those technologies will be effective or forthcoming without a value change that

recognizes explicit goals for and limits to physical growth. Our perception of technology is certainly a bias. We would call it a bias toward lower risk in the conduct of human affairs. We are uncomfortable with the idea of basing the future of our society on technologies that have not yet been invented and whose side effects we cannot assess.[10]

Freeman's third point of difference centers on methodology. He believes that modeling methods are still too primitive to involve them in real decision-making processes. To illustrate his point he lists five properties of the system dynamics approach:

1. It implies a spurious degree of precision.
2. It neglects social factors that are difficult to quantify.
3. It encourages over-simplification by aggregation and by mathematical approximation.
4. It tends to treat some actually variable factors as immutable.
5. It is difficult for a layman to understand or rebut.

Here Sussex' avoidance of comparative statements is particularly misleading. All models, mental or computer, are subject to these constraints. However, anyone comparing the World models to an input-output matrix or a set of regression equations would conclude that system dynamics models are less subject to these faults than the standard economic and econometric models, which are used regularly as inputs to decision-making processes.

To take each of Freeman's points in turn, we state explicitly that we are not interested in precision but in general behavior modes (the statement occurs in six separate places in Limits; we purposely removed the numerical scales from our computer outputs to discourage precise interpretations of numbers we know to be imprecise).

System dynamics models are famous, some might say infamous, for their inclusion of social factors that few others are willing to quantify (examples from the World models include desired completed family size, lifetime multiplier from crowding).

Because system dynamics is a simulation method, no linearities or other mathematical simplicities need be introduced in its models. System dynamics is probably the least mathematically limited of all currently available modeling methodologies. Aggregated models, on the other hand, are often employed by system dynamics modelers, including ourselves, because of our feeling that a system should first be approached from its most general, aggregated properties. Only when these are understood should details be introduced. This feeling stems from strong total-system bias; if we begin with the trees it is too easy to lose sight of the forest, but if we begin with the forest, we can always pause to examine individual trees, if necessary. The emphasis on aggregation expresses our own preferred approach, not an inherent characteristic of the method.

Because of its emphasis on feedback, system dynamics probably treats fewer variable elements as immutable than any other sort of modeling method.

Finally, the method was originally designed to be comprehensible to industrial managers with little mathematical background. It uses one of the simplest simulation languages ever devised, and great effort has been devoted to presenting and describing each model in nontechnical language and clear diagrams to a wide public.

In summary, Professor Freeman's third point accuses the system dynamics method of many of the faults that are characteristic of the models used now for decision-making. The Sussex report implies that precise, comprehensive, detailed, and understandable models are now available to aid in social decisions. Until Sussex provides examples of these models we will maintain our opinion that they are not available. Our own formal models have many faults and we are anxious that they be improved. Our primary concern, however, is that the best possible models available be criticized, revised, and used, so that the quality of our social decisions can progress with the quality of our models.

This brings us to the final point of difference between the groups at Sussex and at MIT, the point we regard as basic not only to this discussion but to all discussions among ecologists, "environmentalists", Malthusians, economists, industrialists, pessimists, and optimists. It is the point Marie Jahoda touches upon briefly in her conclusion - the "conception of man" underlying the World models. Jahoda believes that in the World models man is "pushed by a unified system mechanistically into intolerable conditions". Her own concept of man assumes that he "assesses the circumstances around him and responds actively by adapting his goals and values". Contrary to Jahoda's interpretation, the World models are explicit statements about how global society is currently adapting its goals and values in response to changing circumstances. Indeed the primary objective in the field of system dynamics has been to represent the dynamic effect of shifting goals and values on human decisions and actions.

Let us go on from this false analysis of a misunderstood difference to the real difference in "concept of man" that seems to be dividing the world into camps of "optimists" and "pessimists". One possible concept of man, the one that is held by the Sussex group, 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.[11]

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 developments will occur instantly upon

the perception of the obstacle. 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 future. 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 ugliness, 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.[12]

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4. Meadows, D. L. et. al., The Dynamics of Growth in a Finite World, Wright-Allen Press, Cambridge, Mass., forthcoming Spring 1973. (Limited copies of a preliminary draft of the technical report are available for $60 xerox charge plus $5 overseas airmail from: Publications Office, Research Program on Technology and Public Policy, Thayer School, Dartmouth College, Hanover, N. H., 03755.)

5. SCEP, Man's Impact on the Global Environment, MIT Press, Cambridge, Mass., 1971.

6. Essentially the same claim has been put forward by two other groups, J. W. Oerlemans, et.al., Nature, 238, 251 (1972); R. Boyd, Science, 177, 516 (1972).

7. Jay W. Forrester, "The Fledgling Cheermonger", Cambridge Review, 1973 and Forrester, "Churches at the Transition Between Growth and World Equilibrium" in Toward Global Equilibrium: Collected Papers, Wright-Allen Press, Cambridge, Mass., Jan. 1973.

8. Several have already started, such as Kenneth Boulding, Ezra Mishan, Herman E. Daly, Nicholas Georgescu-Roegen.

9. K. E. Boulding, Economics as a Science.

10. A logical consequence of the Sussex view is illustrated by the current policy on nuclear wastes. Radioactive wastes with half lives of thousands of years are either dumped into the sea or stored in containers with expected lives of 50 years. It is assumed that some technological advance will materialize in time to prevent difficulty.

11. H. J. Barnett and C. Morse, Scarcity and Growth, Johns Hopkins Press.

12. T. R. Malthus, A Summary View of the Principle of Population, 1830.

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10th November, 1972.

Professor D. Meadows,
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New Hampshire 03755,
U.S.A.

Dear Dennis,

I think that you may have mis-understood our request for release of the Technical Report. Our papers submitted to Futures and for later publication by the Sussex University Press are a critique of World Dynamics and Limits to Growth. Our request relates only to the basic assumptions and equations in the World 3 model. These must be the same in all versions of the Technical Report and in Limits to Growth, as I am sure you would not change them after publishing your conclusions based on World 3 in Limits. Indeed from this standpoint, apart from any typographical errors, the early versions of the Technical Report are more relevant than the new draft which you will have in mid-November. We did not anticipate that our request would cause you any problems, which is the reason I wrote in the way that I did: ("Unless we hear from you to the contrary.." etc.). I thought that this was simply a formality prior to circulation of our draft and subsequent publication.

We would of course be very interested in your new draft of the Technical Report and particularly in the new chapters. We would be glad to comment on them to you privately and, after you publish them, in the public literature. But this point should not be confused with our request for your consent to release the model equations and assumptions in the Technical Report for open comment. We understand that you intend to achieve two purposes with your revision of the Technical Report:

(i) to make available the necessary technical data for normal scientific debate on World 3;

(ii) to produce a new book with much new commentary and additional analysis.

We are concerned at the moment only with (i). Forrester published his equations with his book, which of course is the normal scientific practice and it would in our view have been better if you too had published a 'technical appendix' to Limits in the same way. However, we appreciate that there may have been practical difficulties in the way of this. All the same, as I am sure you are well aware, the

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continued delay in release of this technical data is damaging to the reputation of your group, particularly after Carroll Wilson's explicit public statement in Science (23 June 1972) that the report would be released in June. Consequently we really do believe that it would be in your own best interests, as well as in ours, to release the report not later than the end of this month. If you would prefer us to make reference to the final version we will do so, provided we receive it before the end of the month, or if you would prefer it, we will not make any specific references to pages or chapters of the Technical Report, but simply discuss the assumptions.

It is possible that there are issues affecting the Club of Rome which are making you hesitate about the release. In case this is so, we could if you wish immediately send copies of this letter to Dr. Peccei, Dr. King, and Dr. Thiemann, and to our own Vice-Chancellor, who is a member of the Club. I am quite sure that they will agree with us that everyone's best interest will be served by permitting us and any other groups concerned to comment on the basic assumptions of the World 3 model. We would very much prefer to settle this question without any public controversy. Please do not force us to make an issue of this. We would have to do so if we did not receive your clearance in November.

I convinced Freeman this was on fire & unfree

We have now received a contract from the SRC and SSRC to do further work on world models in 1973. I am sure that you will have plenty of opportunity in the future to make your own thorough criticisms of our efforts, and we shall welcome your public criticism, as well as private.

We have acted throughout in the belief that both your group and the Club of Rome were completely sincere in your statements that you wished for a well-informed professional public debate around World 3, even if this involved some strong criticism of the assumptions of the model and your conclusions. You will see in the enclosed draft of our "Acknowledgements" that we pay tribute to you on this very point. Hence our request is simply the standard norm of scientific debate that when important new results are published in any branch of science, qualified researchers should have the opportunity to analyse the experiments and the data critically, and to publish their results too. In view of the first paragraph of your letter I am sure that you will accept this.

We have never hidden from you that we had many deep disagreements and criticisms over World 3. Indeed you spent a day patiently listening to a barrage of comment, criticism and interrogation in July. As you know, many of these criticisms are so fundamental that they would require

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a new model, rather than a new version of the Technical Report, to accommodate them. However, since you specifically request it, I enclose a summary of about twenty of our major criticisms of the World 3 assumptions and structure. We will of course send you the full set of papers as soon as we get your clearance.

I very much hope that as in our July discussions, despite our deep and fundamental disagreement on many of the issues, it will be possible to conduct this debate, both in private and in public, in good faith and to preserve good personal relations between our groups. I realise that this may be difficult, but we would certainly like to keep it that way. For this reason, I welcome your invitation to the Copenhagen meeting, which Dr. Cole or Mr. Curnow will take up. I would like to take the opportunity to thank you again for making available the earlier versions of the 'Technical Report' and for your July visit. Despite any disagreements, you and Dana are welcome in Sussex any time, and I would be very glad to meet you when you are in England.

Yours sincerely,

Chris

Professor C. Freeman

I called Chris Nov. 15 to learn their precise plans.

My cable Nov. 16 read:

I confirm release of technical material for use in February futures and book released March 31. Please send review Meadows at Dartmouth and Forrester at M.I.T.

MEADOWS

We have received nearly one-hundred requests for our technical report. I have given the material only to a few groups. We felt the mental model was not sufficiently well described in the written material for the equations to be of any constructive use except to the groups with which we spent substantial time. It may be worth pointing out that no one at Sussex questioned the ethics of witholding our technical material from the public in July. Quite the contrary, Cournow seemed very pleased to learn that I would not be giving the material to any of the groups competing with you at that time for the SSRC grant. It was also the decision of your group to exclude Burke from our discussions at your laboratory. You mentioned that you would one day be preparing a book analyzing our work. My response was that I welcomed any debate based on our final material. I promised that you would continue to be among the first groups to receive the revised editions of our report. Two months later a friend came back from England with the rumor that the Sussex group was about to publish a book on our model. I didn't even bother to inquire about it because such a book was clearly a violation of the agreement we had made, an agreement which you found eminently satisfactory in July. Since I had not received a single page of analysis from your group, I assumed none existed. I was surprised when I received a copy of Sinclair's speech before the world meeting of Futurists not from Sussex, but from a Dartmouth colleague who had been at the meeting. Then, long after you had personnally committed yourself to prepare a Futurist issue, I got a request to use the "equations" in a few "papers." A few days after that, an American publisher called to announce that he had been offered the rights to a book by your group. When I sent a letter essentially repeating our understanding, I received a letter from you which expressed some new-found distinction between the "equations" of World 3 and the technical report and which threatened "public controversy" if we did not immediately release the material I had provided your group. When I asked you over the phone for a copy of the material, I was told that I could only obtain a copy of it if I signed a blanket release of the equations for your use. If this is the British form of scientific cooperation, then I wish you would start cooperating with Deckerman and Maddox. As a result of my efforts to support the work of your group, I found myself in an extremely unsatisfactory situation with essentially no choice. After agreeing with your demands, I received a roughly three-hundred page manuscript which completely denied any scientific merit to the work which Dana and I and our group have invested two