IIASA COLLABORATIVE PROCEEDINGS SERIES

CP–82–S7

ENVIRONMENTAL ASPECTS IN GLOBAL MODELING

IIASA COLLABORATIVE PROCEEDINGS SERIES

CP–81–S1 LARGE-SCALE LINEAR PROGRAMMING
Proceedings of an IIASA Workshop
G.B. Dantzig, M.A.H. Dempster, and M.J. Kallio, *Editors*

CP–81–S2 THE SHINKANSEN PROGRAM: TRANSPORTATION, RAILWAY, ENVIRONMENTAL, REGIONAL, AND NATIONAL DEVELOPMENT ISSUES
A. Straszak, *Editor*

CP–82–S1 HUMAN SETTLEMENT SYSTEMS: SPATIAL PATTERNS AND TRENDS
Selected Papers from an IIASA Conference
T. Kawashima and P. Korcelli, *Editors*

CP–82–S2 RISK: A SEMINAR SERIES
H. Kunreuther, *Editor*

CP–82–S3 THE OPERATION OF MULTIPLE RESERVOIR SYSTEMS
Proceedings of an International Workshop, Jodlowy Dwor, Poland
Z. Kaczmarek and J. Kindler, *Editors*

CP–82–S4 NONPOINT NITRATE POLLUTION OF MUNICIPAL WATER SUPPLY SOURCES: ISSUES OF ANALYSIS AND CONTROL
Proceedings of an IIASA Task Force Meeting
K.-H. Zwirnmann, *Editor*

CP–82–S5 MODELING AGRICULTURAL–ENVIRONMENTAL PROCESSES IN CROP PRODUCTION
Proceedings of an IIASA Task Force Meeting
G. Golubev and I. Shvytov, *Editors*

CP–82–S6 LIQUEFIED ENERGY GASES FACILITY SITING: INTERNATIONAL COMPARISONS
H. Kunreuther, J. Linnerooth, and R. Starnes, *Editors*

CP–82–S7 ENVIRONMENTAL ASPECTS IN GLOBAL MODELING
Proceedings of the 7th IIASA Symposium on Global Modeling
G. Bruckmann, *Editor*

ENVIRONMENTAL ASPECTS IN GLOBAL MODELING

Proceedings of the 7th IIASA Symposium on Global Modeling

G. Bruckmann, Editor

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria
1982

International Standard Book Number 3-7045-0049-6

This volume in the *Collaborative Proceedings Series* contains selected, revised papers first presented at an IIASA conference. However, the views or opinions expressed do not necessarily represent those of the Institute, its National Member Organizations, or other organizations supporting the work.

Copyright © 1982 International Institute for Applied Systems Analysis, except pages 7–14 which are British Crown Copyright and reproduced here by permission.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

PREFACE

In the field of global modeling, the International Institute for Applied Systems Analysis (IIASA) has, ever since it was founded in 1972, assumed a monitoring role. Whenever a major model was approching completion, IIASA convened a conference in which the model was presented and discussed. The Fifth Global Modeling Conference deviated slightly from this pattern in that it focused on an approach (input–output modeling) rather than on a particular model. The Sixth Conference was devoted to a general assessment of the state of the art. Details of the proceedings of these and earlier IIASA Global Modeling Symposia are given on the next page.

The Seventh Global Modeling Conference was different again in structure: it concentrated on a key problem that, it was felt, deserved special attention, namely, the role of the environment in global modeling. The purpose of the Conference was not so much to look back on what had been achieved (or remained to be done), but rather to examine what should be learnt for future modeling work from past achievements or omissions. It is hoped that the papers presented in this volume will give an overview of the problématique and of possibilities for future advances.

Permission from the copyright holders to reproduce some of the papers and a number of the figures in this volume is gratefully acknowledged.

Gerhart Bruckmann
Editor

PROCEEDINGS OF IIASA GLOBAL MODELING SYMPOSIA

M. Mesarovic and E. Pestel (Editors) (1974). *Multilevel Computer Model of World Development System*. Summarized Proceedings of the Symposium, 29 April–3 May 1974. CP-74-1. International Institute for Applied Systems Analysis, Laxenburg, Austria.

G. Bruckmann (Editor) (1976). *Latin American World Model*. Proceedings of the Second IIASA Symposium on Global Modeling, 7–10 October 1974. CP-76-8. International Institute for Applied Systems Analysis, Laxenburg, Austria.

G. Bruckmann (Editor) (1977). *MOIRA: Food and Agriculture Model*. Proceedings of the Third IIASA Symposium on Global Modeling, 22–25 September 1975. CP-77-1. International Institute for Applied Systems Analysis, Laxenburg, Austria.

G. Bruckmann (Editor) (1978). *SARUM and MRI: Description and Comparison of a World Model and a National Model*. Proceedings of the Fourth IIASA Symposium on Global Modeling, 20–23 September 1976. Pergamon Press, Oxford, UK.

G. Bruckmann (Editor) (1980). *Input–Output Approaches in Global Modeling*. Proceedings of the Fifth IIASA Symposium on Global Modeling, 26–29 September 1977. Pergamon Press, Oxford, UK.

D.H. Meadows, J. Richardson, and G. Bruckmann (Editors) (1982). *Groping in the Dark: the First Decade of Global Modeling*. Including the Proceedings of the Sixth IIASA Symposium on Global Modeling, 17–20 October 1978. Wiley, Chichester, UK.

G. Bruckmann (Editor) (1982). *Environmental Aspects in Global Modeling*. Proceedings of the Seventh IIASA Symposium on Global Modeling. CP-82-S7. International Institute for Applied Systems Analysis, Laxenburg, Austria.

B.G. Hickman (Editor). *Global International Economic Models*. Selected Papers from the Eighth IIASA Symposium on Global Modeling, 22–25 July 1980. (Forthcoming.)

CONTENTS

Climate, Air Quality, Energy

Resources

Other Modeling Work

WELCOMING ADDRESS

R.E. Levien
International Institute for Applied Systems Analysis, Laxenburg (Austria)

This is the seventh conference in a series that IIASA began in 1974, a series that has been devoted to exchanging information among groups working on global modeling. We have tried, as an Institute concerned with issues of global scale, to provide a forum in which the groups that have been developing models of global phenomena can describe the work they have done to their colleagues in an environment in which informal interaction is encouraged.

The last conference was an attempt to summarize what had been learnt in the previous five conferences and to reach some general conclusions about the state of the art and its future development. This conference begins a second series; as you know, it is dedicated to a particular issue: the treatment of environmental questions within global models. We are already planning the conference to be held next year; it will be devoted to the treatment of economic issues in global modeling: international economic modeling. So as you can see, we have a commitment to the further continuation of this series of conferences.

Now, before turning to the business of the Conference, let me give the newcomers among you a brief introduction to the Institute. In December 1966 it was proposed that an institute might be created to work on the common problems of the developed countries. This proposal came from the United States, but was quickly followed by discussions with the Soviet Union. In early 1967 the Soviet Union agreed to participate jointly with the United States in establishing this Institute. During the course of negotiations, which took five years, a number of additional nations agreed to participate. By the time the charter was signed on October 4, 1972, there were 12 National Member Organizations (NMOs). Scientific activity began in June 1973. The First IIASA Conference, which the Charter requires to be held on a periodic basis to review the work of the Institute and to obtain inputs from outside, was held in May 1976. After it, three more NMOs joined the Institute, bringing the total to 17. (The Austrian and Hungarian NMOs had joined in 1974 and 1975.) We have a Second IIASA Conference planned for May, 1980.

The founders of IIASA left us a valuable heritage, comprising four features:

(1) IIASA is *nongovernmental*, which makes it possible to discuss potentially controversial issues in a nonpolitical setting.

(2) IIASA is devoted to *applied systems analysis*, a phrase that our founders understood to mean that IIASA was to be concerned with the application of science and the methods of science to important practical problems.
(3) IIASA is located in Austria. We have been very well treated by the Austrian authorities. This Schloss, which is a Maria Theresia building dating from the middle of the 18th century, has been renovated at a cost of 170 million Austrian schillings: the Austrian government rents it to us for 1 schilling a year.
(4) IIASA is supported by annual contributions from its national member organizations. Since the United States and the Soviet Union had the original idea, their NMOs have the privilege of paying more! This year they paid 30.5 million Austrian schillings, and the other NMOs each contribute 15 percent of this amount. Thus, NMO dues annually provide us with about 130 million Austrian schillings, which at the current exchange rate is equivalent to roughly 10 million US dollars.

A second aspect of the founders' heritage was the high aspirations that they set for IIASA. These take the form of three goals: First, to achieve and to facilitate international cooperation – joint work by scientists in countries around the world on common problems. Part of this work is accomplished here at IIASA by a scientific staff of about 95, but we have also been able to fulfill the founders' ambition of using IIASA as a core around which an international community can build. Consequently, much of the Institute's work is being done outside of the Institute, but in conjunction with it. Our second goal, because we were founded by Academies of Science and similar bodies, but also because we have high goals of our own, is to contribute to the advancement of science and the state of the art of systems analysis. Our third goal is to apply our efforts to problems of international importance. We distinguish, although they are not always distinct, between "global" and "universal" problems.

Global problems cut across national boundaries and cannot be solved without the work of several nations jointly. For example, protection of the global climate from the impact of carbon dioxide is not a single-nation problem, it is a truly global problem. We have chosen as a theme for IIASA the issue of global development: how is the world going to deal with a doubling of its population; how are increased needs for energy, food, minerals, housing, and for the health and education services that human beings require for a decent life going to be met as the population doubles? We have chosen to approach these problems not in a totally comprehensive manner but rather on a sectoral basis. We are looking first at energy and at food and agriculture. We have two major research programs addressing these issues.

Secondly, there are *universal problems*, which lie within national boundaries, but which are important for IIASA because all nations share them. These may be the problems of pollution of the environment or regional energy and environment interaction or they may be problems of designing a health-care system. IIASA has a role to play for such problems in exchanging experience in their solution and in their analysis among countries which differ considerably in social, economic, and political backgrounds.

The other characteristic of IIASA's work in studying these problems is the adoption of a *comprehensive approach*, by which we mean one that is disciplinarily comprehensive. When studying energy, for example, we engage not only the point of view of the energy technologist but also that of the economist, environmentalist, and demographer. We try to incorporate the insights of many different disciplines in our work. This has led us to a matrix form of organization with two cross-cutting programs, one addressing global energy futures and one addressing global food futures, and four basic research areas which provide the disciplinary skills for the cross-cutting analyses. The Resources and Environment Area, chaired by Oleg Vasiliev, is concerned with the earth's natural endowment. The Human Settlement and Services Area, led by Andrei Rogers, is concerned with the earth's human endowment. The Management and Technology Area, led by Rolfe Tomlinson, is concerned with man-made contributions to the global endowment. And the System and Decision Sciences Area, led by Andrzej Wierzbicki, is concerned with the methodology for the analysis of complex systems and decision procedures. We also have a category, called General Research, whose function is to be the home for prospective programs and other cross-cutting activities. Gerhart Bruckmann, who leads the Global Modeling conference task, resides in General Research. Because I am interested in these cross-cutting topics, that is my area of responsibility. The research "task" is the basic unit of research at the Institute. There are about 25 of these tasks, ranging over topics such as environmental problems of agriculture; health care systems; risk management; population, resources and growth; economic planning; optimization; and so on. As you can see, there is a rather broad range of activities underway at the Institute.

Our resources comprise about 75 scientists paid for by our national member organizations; this marvellous Schloss, plus a new office building; a library which is relatively modest – about 500 journal subscriptions and 9,000 books – but which has very close links with libraries and information services around the world; and computing facilities, comprising a PDP 11/70 here at IIASA, supplemented by contacts and direct leased lines to Pisa, Italy, where there is an IBM 370-168, and to the Technical University in Vienna, where there is a Cyber 74. Next year a leased line is going to Moscow via Bratislava and Prague, and another one to Budapest, all of which will serve to make IIASA a gateway among computing facilities and networks in East and West. The most important point about IIASA's resources is that our policy is not to be a self-contained facility, but rather to use the group of 75 scientists as a core around which, an international network of activities is structured. Each year, for example, we have about 10 guest scholars, who come from industry or on fellowships. We have external funds from UN agencies, from various foundations, and from industry that enable us to hire another 15 or so scientists. So in fact, our total scientific staff at IIASA is between 95 and 100 each year.

However, the most important extension of our efforts is through collaborative research, work done jointly with other institutions around the world. In our Annual Report for 1978 we listed 220 such institutions from 25 countries; more than twice as many collaborative links as there are scientists at IIASA. Many of them provide more manpower. For example, our Food and Agriculture Program has collaboration with about a dozen institutions. There is far more work in total going on in this collaborative net than at IIASA itself, but it is the total work which is important for the accomplishment of our goals. We also try to catalyze research which is work done outside of IIASA as a result of IIASA's initiative or of interests established here, but not performed in conjunction with our research plan. Some of this is undertaken by alumni who continue work at their home institutions which they began here. Finally, there is the function of IIASA as a facilitator of information exchange. This conference is one of 30 or so that we hold each year; about 1000 participants come here for these conferences. In addition, we have 700 visitors each year who come for periods of a day or several weeks. We publish books in a series with John Wiley and Sons, as well as conference proceedings with Pergamon Press. There are about 100 IIASA publications of various forms each year, as well as a large number of publications in the journal literature.

So, as I welcome back those of you who have been regular participants in this series of conferences, I should also like to welcome those of you who are here for the first time. We hope that you will join with the colleagues here and become regular participants of the work of the Institute, not only in this conference, but also through our collaborative network. Perhaps you will some day join us as members of our longer-term scientific staff. I wish you success in your meeting, which I am sure will be both fruitful and interesting.

INTRODUCTION TO THE CONFERENCE

Gerhart Bruckmann
International Institute for Applied Systems Analysis, Laxenburg (Austria)

Last year's Global Modeling Conference differed from earlier conferences in that it was not devoted to a presentation and discussion of any one particular model or approach, but was of a cross-cutting nature, trying to assess the state of the art. During the discussions at that Conference, it became apparent that, within the field of global modeling, several main topics had not received as yet the attention they deserve. The most prominent of these topics was the environment. Global modelers had, so far, for the most part either omitted environmental factors altogether or treated them in summary or in a haphazard way (the only model explicitly taking environmental factors into account being the Leontief model).

Needless to say, there was good reason for this neglect. Ecologists are themselves only beginning to understand the complex relationships of their craft; if even the "best available experts" in the field are not too sure yet about a possible greenhouse effect due to increased CO_2 concentration, or about the influence of other sources of thermal pollution on world climate, how can the impact of the results of these uncertainties upon economic or demographic variables in a global model be assessed? On the other hand, to close our eyes to these impacts implies tacitly that they don't exist, and any forecast based on a global model omitting ecological considerations is bound to be either very far wide of the mark or at best a worthless mental exercise.

So, the goal of this Seventh Conference was clear; it was entirely unclear, though, how this goal could be achieved. Even the format of the Conference was open: should the sessions be categorized by life support systems (agricultural production, fuel woods, oceans, atmosphere), by factors affecting ecological changes (climatological–natural and made-made, biochemical–natural and man-made, direct interventions like deforestation or over-grazing), or by mode of treatment? Where are the boundaries of the topic – should human diseases or animal and plant diseases be included or excluded?

At this stage of the presentation, the advice given by Jennifer Robinson and Peter Roberts proved particularly fruitful. From many discussions, there finally emerged a conference scheme which now looks quite simple. The Conference brings together, maybe for the first time in a deliberate fashion, global modelers and ecologists. In the first part of the Conference, the modelers will tell the ecologists about their (successful and unsuccessful) attempts to map environmental processes in their global models. In the second part, the ecologists will have their say; they will, we hope, furnish constructive criticism of what they have heard, and tell the modelers about the state of the art of their discipline, in the most important ecological fields: food and agriculture, climate, air quality, energy, and resources.

At the beginning of this Conference, I feel obliged to mention – in the presence of the Director of IIASA – an additional difficulty: the lack of travel money. The non-existence of travel funds in the IIASA global modeling conference budget did not present any difficulties at earlier conferences: the modelers who were invited to present their model were eager to do so and provided for their own funds, the other participants were eager to learn about a newly emerging global model (or maybe just eager to see their old friends again) and came at their own expense too. So, the "global modeling community" had become accustomed to paying its way to IIASA, but this could definitely not be expected from the community of ecologists, many of whose attitudes toward global modeling range from indifference to hostility. As a result, I have to admit frankly that the participation of this Conference is not as balanced as I would have wished it to be: the global modelers outweigh the ecologists. At IIASA, however, we have accumulated ample experience in making virtues out of necessities: this smaller number of participants will allow us to conduct the Conference more or less as a workshop: few prepared papers but more time for discussions. And maybe it will be these discussions that will, in retrospect, be considered the main outcome of the Conference. Let us begin, therefore, in the open and constructive spirit that has prevailed in all earlier IIASA global modeling conferences!

RESILIENCE, TRANSIENCE, AND SUSTAINABILITY*

P.C. Roberts
Systems Analysis Research Unit, Departments of the Environment and Transport, 2 Marsham Street, London SW1P 3EB (UK)

1 WORLD 2 AND ITS CRITICS

The first World model, which was devised by Forrester (1971), contained the most important elements of the environmental dimension, in spite of the fact that it was a very simple model with few variables and relationships. The first basic truth embodied in World 2 was the concept of the exhaustibility of resources, and although critics have been quick to point out that matter is conserved so that the "consuming" of resources is a misnomer, nevertheless the degradation of concentrated materials through dispersion is a real entropic process. If some essential element is mined at high concentration and is later discarded at low concentration then it is only a matter of time before the process must be exchanged for one that is less irreversible.

The second basic truth is that waste from consuming activities must be absorbed by the environment. This applies even to a primitive society doing little more complicated than eating. The waste products (carbon dioxide, urea, etc.) are processed within the biosphere and reappear as oxygen, carbohydrates, and protein. Finally, the structure of World 2 contained a mechanism that reduced the capacity of the environment to absorb waste according to the rate of waste discard occurring; i.e. it contained the idea of poisoning of the sink through an excessive discharge. The current view among critics of World 2 who are also environmentalists is that the problems thrown up by the Forrester model can be solved by a combination of recycling and legislation of the "polluter pays" variety. It is argued that by reusing materials the rate of required exploitation is reduced and also the rate of discharge of waste products to the biosphere is attenuated. Furthermore, "polluter pays" legislation will force abatement technology so that the environmental impact of waste materials which cannot be recycled will be so diminished as not to matter. I suspect that both these beliefs are ill-founded and for reasons which do not require special models to demonstrate them.

© British Crown Copyright.

* The views expressed in this paper are those of the author and do not necessarily coincide with those of the Departments of the Environment and Transport.

After researchers had experimented with World 2 and had shown that the collapse mode was inherent in the assumptions, it was pointed out that the use of a limited stock of natural resources which was eroded away by the normal activities of human society inevitably drove the model to collapse and that one did not need a model at all to make such a patently obvious point. In the same way, it is unnecessary to construct a model for the purposes of investigating the effect of recycling. If half of material X is recycled after use, X will last twice as long. If nine-tenths of X is recycled, X will last ten times as long, and so on. Why not then seek to recover such a high proportion that the stock is effectively everlasting? The answer is that in engineering terms such a solution is impracticable and one can dismiss ideas of recycling 99.99% of X as merely theoretical. It is not just a matter of technical progress because the problem of maintaining very high concentrations is, like similar problems of eliminating heat loss, making frictionless machines, etc., a fight against rising entropy. The only sustainable system is one in which there is a constant processing of the low-concentration waste (i.e. of the material which has "escaped" into the environment) to recreate high-concentration material. This is analogous to accepting the steady loss of heat from a house which is maintained at a temperature higher than that of its surroundings (in spite of a thick layer of insulating material) and feeding in a stream of energy to sustain the temperature difference. The carbon cycle in the biosphere is a good example of sustained flow to maintain concentrations. In vegetable matter the carbon is present at a density of about $10^{-1}\,\mathrm{kg\,l^{-1}}$. After combustion or decay the resulting carbon as carbon dioxide in the atmosphere is present at about $10^{-7}\,\mathrm{kg\,l^{-1}}$. Through the energy of photosynthesis, oxidizable carbon compounds are reformed with an accompanying increase in concentration again.

The transience of the fossil-fuel era is readily accepted because it is obvious that the burning of carbon changes its state by degrading it to a lower level of potential energy. We speak of "using up the accumulated capital stock of oil and coal" and this is contrasted with "living off income" (corresponding to the use of wind, waves, and biomass). It is less often noted that the mining of metal-bearing ores and the discard of waste metal to the environment is a close parallel in that much less energy is needed for this operation than for one which is sustainable, for example through the concentration of metals from clay or sea water. Thus the mining of high-concentration deposits is a transient occupation in exactly the same way as the mining of coal – the only difference is one of time scale, with most metals having a longer exploitable life than coal at present rates of use.

2 THE POLLUTER PAYS

The second part of the recipe offered to overcome the problems of environmental damage entails legislation to force the polluter to pay the full cost of any damage which he causes. These charges will be passed on to the consumer via high-priced products and this will cause discrimination against such products accompanied by a search for alternative nonpolluting products. Hence, it is argued, the rise of environmental damage can be halted. Now the difficulty of applying this policy is that loading the cost of a product highly enough to make complete abatement worthwhile causes such an adverse market reaction that the viability of the industry is threatened – jobs will be lost, assets have to be written off, and recession looms. As soon as this is understood, the concept of social cost is argued to be as important as that of environmental cost. "What is the benefit of unspoilt countryside if the people who are to enjoy it do not have jobs?" is a question that arises. In practice, therefore, a tradeoff is struck so that the viability of the industry is preserved: if growth of output occurs then there is progressive environmental deterioration. Hence again there is little to be gained by demonstrating the operation of this sequence through a model. The principle of internalizing costs is not in question; it is the supposed mechanisms that are suspect. If a society evolves to the point of rejecting a barbarous practice such as suttee (the self-cremation of Hindu widows on their husbands' funeral pyres) then passing a law forbidding it is merely an outward and visible sign of the inner change. Taxing polluters, like imprisoning criminals, is incidental rather than material to the progress of society, and the experience of prohibition in the United States showed that trying to make people virtuous by statute is not practical.

The stalemate from "polluter pays" is a kind of mental blockage that prevents the envisaging of alternatives and it has many vivid historical precedents. The intellectual society in the city states of ancient Greece could not imagine the possibility of civilized life without slaves. The factory owners in 19th-century England expected that laws passed to ameliorate the lot of the workers would make production uneconomic. Arguments against women's franchise appeared to be compelling at the time of their enunciation. Similarly, the current view is that our way of life would be threatened if we were cut off from fossil fuels, metalliferous ores, the license to destroy virgin forest, and the freedom to dump all our waste products into the atmosphere, the soil, the waterways, and the oceans. This is just as much an illusion as the opinion of Aristotle that the cultured life was only possible with slaves.

3 SUSTAINABLE SYSTEMS

Escape from the illusion lies in the realization that sustainable systems are possible, i.e. that human societies can live in ways that disturb the environment no more than flocks of other mammals – indeed that disturb the environment considerably less than most flocks of mammals. Positive action to escape depends on perceiving that the nondisturbing mode is "better" in the same way that societies without tyranny and oppression are "better" than those that are still tyrannized and oppressed. Action does not depend on arguments within a theme of exploitation. For example, it is argued that destruction of tropical forest in the Amazon basin is bad because there are very many undiscovered plants there that possibly contain compounds of medicinal benefit. This is rather like opposing murder on the grounds that it results in mess from the dead bodies strewn about. Eckholm (1978) quotes an estimate that probably at least one species is disappearing each day in tropical forests alone and that in a few more years there may well be a species lost each hour. Murder and species extinction are both enormities and the realization of that truth is not aided by trivial arguments. The role which models play in the transition phase of a society between its exploitative phase and its succeeding equilibrium phase is that of describing and demonstrating feasibility. If it is possible to show that the equilibrium state is practicable and that a trajectory linking the current state with the equilibrium state can be found then the reality of an alternative option is conveyed. This is not sufficient of itself to generate change – there must also be present awareness of the desirability of change.

4 MODELS OF SUSTAINABLE SYSTEMS

The models themselves are constrained in several ways.

(1) The first requirement is sustainability, and that entails a set of equilibrium cycles for all the materials. Any process which degrades a stock of material at high concentration to a stock at low concentration without also having the reverse process present must be considered as transient; i.e. it is a temporary expedient which is possible only for the interim period before a regime of sustainable systems supersedes. For example, the practice of mining phosphates from the deposits left by seabirds over past millions of years in order to fertilize land from which these phosphates will be washed into the rivers and ultimately the sea is not sustainable according to the definition used here. The production of noxious wastes is the complementary activity of material degradation. Lead is a relatively rare element in the earth's crust but there are lodes of quite high concentration and these are mined to provide the metal and its compounds for artifacts and processes. The end result of this activity is the dispersion of low-concentration lead into air, water, and soil where it becomes a low-level poison. Many wastes are biodegradable: e.g. oil slicks on the sea's surface are digested by microorganisms. Such processes clearly widen the range of cycles which are sustainable.

(2) The second requirement is that the sustainable material cycles can be operated within the range of an energy flow which is itself sustainable. For example, the replacement of the nitrogen lost from the soil by nitrates fixed from the nitrogen of the atmosphere is probably a sustainable material cycle. (There is a doubt about it because the nitrous oxide liberated may be damaging the ozone layer.) However, if the fixation process uses fossil fuel, as in current practice, then the cycle is clearly not sustainable.

(3) The third requirement is that the cycles devised to meet the constraints defined in (1) and (2) are suitable for maintaining populations of the order of 10^9 to 10^{10} people. Hunter–gatherer regimes are sustainable at perhaps one person per square mile, allowing only a few million people at most. Slash-and-burn agriculture in clearings, practiced at low density and with a period of 15 years for the forest to recover, appears to be sustainable and to allow a higher population. For much higher population densities, Leach (1975) notes that preindustrial Chinese peasant farming was made sustainable through effectively closing the material cycles. Many modern agriculture regimes are clearly not sustainable because they involve erosion, or salination, or very large energy subsidies.

(4) There is a further requirement involving resilience. The current practice of using halogenated hydrocarbons as pesticides has one important defect in that resistant strains of pests which develop rapidly make the useful life of a given compound very short and the range of potential compounds is shrinking fast. Apart from this lack of sustainability, the very narrow genetic base of modern high-yielding varieties makes the agriculture based on it vulnerable to devastation through insect and virus attack. In its search for "efficiency" – which is usually to be interpreted as low labor requirement – modern society has moved towards systems of increasing vulnerability. Sustainability entails a high degree of resilience which, in imitation of the methods used by living organisms, is provided by massive redundancy of the components, flexibility of form, and error-correction techniques rather than high-precision machinery.

5 THE TRANSIENT STATE

The requirements for a sustainable system do not define a unique specification but rather a broad band of possibilities. However, in order for the sustainable state to be accepted as physically possible and realizable it is necessary to put flesh on it, i.e. to visualize a possible specification translated into hardware or, in the language of an earlier era, to write a utopia. Such a scenario-writing operation is certainly a contribution but is not of itself likely to generate change without a convincing course charted through the present transient state to a later sustainable one. The role of a quantitative model is to contain all the concurrent changes which must occur for the transient state to be navigated successfully. There is necessarily a set of changes rather than single substitutions because, as with the emancipation of women, the era which succeeds is the embodiment of a principle and not a mere shift of product (like butter to margarine). Despite the fact of a multitude of changes the means of studying and describing the period of transience need not contain so much detail as to be impenetrable. A good example of austere description is offered by Pry (1973) with his plot of urban living versus rural living in the United States reproduced in Figure 1. By regarding one style of life as competing with another and therefore possibly subject to the competing-products logistic law, the time trajectory of the change is captured. Although a whole complex of changes (in livelihood, environment, recreations, acquaintances) occurs as an individual moves from rural to urban living a description in terms which are readily understood is still possible. A form of scenario writing designed to capture the significant features from a complex of changes is that used by Chapman (1975) in his parable "The Isle of Erg". His parable is concerned with objectives similar to the sustainable society but he has concentrated on the aspect of low energy use.

The transient period as we approach the end of the fossil-fuel era could evince change in different sorts of ways. There could be a general reappraisal affecting the whole of society and across the major regions. Alternatively there could be a strong lead taken by one country with a long period for the conversion of the remainder. Conceivably the change could be closely associated with a particular generation so that only when the older generation occupying controlling positions and imbued by the right-to-exploit ethic dies off can the new philosophy flower. The distinctions between these courses are not trivial because the time scales of change are strikingly different for those requiring new generations to adopt new life styles. The rural–urban shift studied by Pry has a T value (from 10% to 90% of the market) of 220 years. In contrast, the switch from coal-fueled to diesel-fueled locomotives has a T value of about 10 years because no change in life style is involved. A good case can be argued for believing that the nearer a product comes to requiring a change in outlook, the longer is the T value.

6 THE USE OF MODELS

Given that a society could change from an exploitative mode to a sustainable one, a range of issues can be studied through simulations of the transient period.

(1) Identification of the stress areas can be made. For example, a slow replacement of fossil-fuel use by alternatives may run into difficulties simply because the substitution

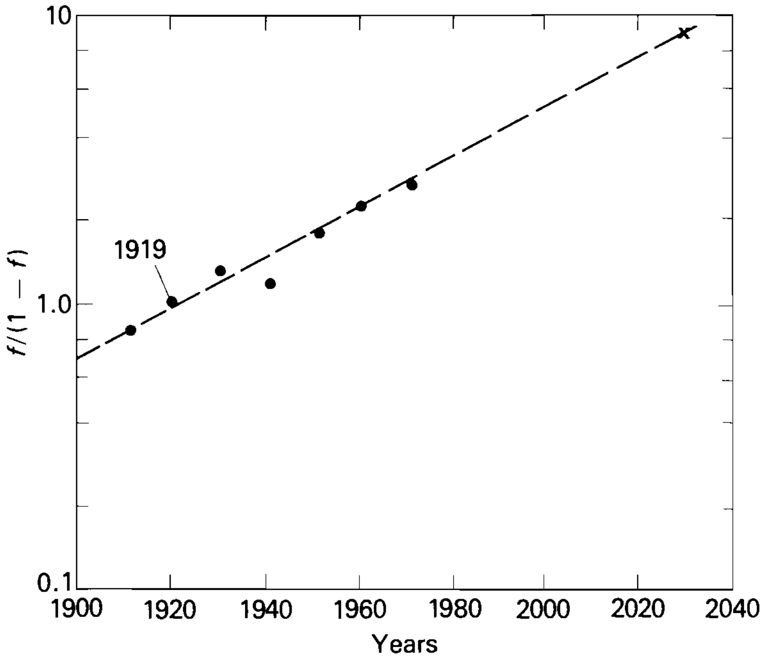


FIGURE 1 Urban versus rural living in the United States (T = 220 years) (after Pry, 1973).

comes too late to offset shortages. The abandonment of despoiling practices may be too slow to prevent loss of major biospheric resources.

(2) Secondary effects associated with the changeover may be disruptive. For example, it is evident that patterns of employment will be altered significantly. There is no necessary association between the level of skill requirement among the operators and the degree of sustainability of a system. Patterns of trade will clearly be changed drastically and if the changes are compressed to a brief schedule this could generate hardship.

(3) The spread of the new ethic can be simulated by regarding it as a new set of preference functions associated with a small but growing number distributed among the populace. The spread of some previous attitudinal changes may provide suitable parallels on which to base the parameter values needed for this simulation.

(4) The effects of legal and fiscal measures mirroring the attitudinal changes can be simulated. It is noticeable that changes in outlook across society are reflected in new legislation. For example, there has in recent years been a rising widespread distaste for the wholesale killing of whales. The overt result of this rising concern has been internationally agreed restrictions on whaling.

(5) It has sometimes been argued that a society prevented from growing, in terms of its material output, must suffer economic troubles, particularly unemployment and decline. A sustainable society may grow in all sorts of ways but certainly not by increase of its material output. On the face of it the thesis is improbable when one contemplates the activity in a tropical forest because forest ecosystems appear sustainable over immense periods of time.

7 CONCLUSIONS

Contemporary industrial activity is omnipresent, pervasive, and inescapable, so that it is difficult to recall how recent is its rise. For thousands of millenia living systems, including creatures recognizably human, have flourished here in resilient sustainable systems with the various vital elements cycling and recycling through the biosphere. Now in this little space of less than one millenium there has been an explosion of exploitative nonsustainable activity. Either it will continue similarly and destroy itself or it will be modified to a new variety of resilient sustainable system. Modelers – specifically global modelers – may have a role to play in charting a course through the transient period and into the age that lies beyond.

REFERENCES

Chapman, P. (1975). Fuel's Paradise: Energy Options for Britain. Penguin Special, London.

Eckholm, E. (1978). Disappearing species: the social challenge. Worldwatch Paper 22. Worldwatch Institute, Washington, D.C.

Forrester, J.W. (1971). World Dynamics. Wright–Allen, London.

Leach, G. (1975). Energy and Food Production. International Institute for Environment and Development, London.

Pry, R.H. (1973). Forecasting and diffusion of technology. Technical Information Series, No. 73CRD220. General Electric, Schenectady, New York.

DISCUSSION

Kamrany, *in opening the discussion, pointed out that, as well as the overall question of growth, the existing disparities between different regions of the world have to be considered. The question of growth cannot be treated independently from the question of meeting basic needs anywhere.*

Roberts *agreed that there is no point in discussing long-term sustainability if one cannot even survive until the day after tomorrow. However, the immediate concern of reducing the existing discrepancies should not obscure the long-term goal of sustainability.* Meier *pointed out that the problem lies also in the fact that the poor are unable to care about the environment while the rich tend to solve their own environmental problem by exporting it to the poor countries.* Roberts *agreed: presently, the price that the poor pay for their survival is often a deterioration of their own situation tomorrow.*

Steger *and* Meier *asked* Roberts *about the kind of equilibrium model that he had in mind; does sustainability mean static or dynamic equilibrium?*

Roberts *replied that he would prefer to see this question from a pragmatic angle: what is important is a change in the general direction of further growth. If we accept sustainable growth as a normative goal then our concern should be about the ways and means of achieving it.*

Snower *contested the necessity to limit material output, even over a long period of time: technological progress has enabled man to expand his activities much farther than had been expected in earlier times (Malthus) and there is no reason to assume that this proposition will not hold equally in the future (waste products could be systematically* *recycled, synthetic fuel developed); technological breakthroughs could permit continued material growth for extremely long periods of time before the entropy problem arises.*

Bruckmann *continued this line of reasoning: could it not be envisaged that the deliberate use of renewable energy sources (solar) would allow mankind a much higher rate of material throughput, coupled with higher sustainability, than that which we could afford with present technology?*

Roberts *opined that such a path would only mean a temporary shift of the basic problématique. If carried through this path would, furthermore, come close to what he himself envisages as the path toward sustainability.*

Mesarovic *pointed out that the problem in reality is much more grave: already today we may be consuming more than we should. It is a fact that per capita production of food in Africa has been declining over the last five years. In his opinion it is impossible to continue to increase material consumption to a point at which a doubled world population would enjoy the present consumption level of the developed world. This, precisely, is the purpose of our models: to separate the realm of possible paths into the future from the realm of impossible ones.*

Kamrany *came back to* Roberts' *statement that most global models so far have limited themselves to investigating minor changes. Must not the changes proposed in, say, "Limits to Growth", be regarded as major ones? In reply,* Roberts *clarified that, in spite of the impact that "Limits to Growth" certainly had, most people nowadays still think that minor adjustments here and there will suffice.* Mesarovic *seconded this view: one problem with global models is that they propose changes that cannot come about without a basic paradigm change, which, however, is not reflected in the models. Hence one is misled to believe that certain adjustments will suffice.*

GLOBAL MODELING – A USER PERSPECTIVE

Wilbur Steger and Nazir Dossani
CONSAD Research Corporation, 121 North Highland Ave., Pittsburgh, Pennsylvania 15206 (USA)

Ted Williams and Peter House
Division of Policy Analysis, Office of Environment, US Department of Energy, 1000 Independence Ave., Washington, D.C. 20585 (USA)

1 INTRODUCTION: FOCUSING ON THE USE OF GLOBAL MODELS

1.1 Background

Previous IIASA meetings have focused on facilitating communications between global modelers who are interested in describing and discussing each other's models, thus enhancing the role of IIASA in monitoring global model development (for example, see Bruckmann, 1978). The tradition of meeting to discuss assumptions, methodology, and model findings has continued with this seventh conference in the series. Such focusing on the modeling "supply" side is readily understandable, the interests and capabilities of professional economists and systems analysts being what they are. Furthermore, until it became more obvious – as we believe it has become during this last decade – that a variety of potentially useful and reasonably valid global models exists, there seemed to be little need to pay attention to the "demand" side for modeling. We believe it is now time to do so and, in the interest of remedying (at least partially) this imbalance, we will devote our primary attention to the demand side or "users' side" in this paper.

We are cognizant and conversant with the nearly half-dozen or so major global modeling efforts: IIASA's energy-focused set of MACRO, IMPACT, MEDEE, and MESSAGE (Basile, 1979, pp. 4, 5; MEDEE and IMPACT have been adapted by IIASA, building on the work of others at the University of Grenoble and the Siberian Power Institute, respectively); the Systems Analysis Research Unit Model (SARUM) (United Kingdom) and the MRI model (Poland) (Bruckmann, 1978); the Meadows–DYNAMO world models sponsored by the Club of Rome; Project LINK; and a variety of other econometric, simulation, and/or mixed global modeling systems, including Leontief's nested interindustry economic–environmental modeling effort for the United Nations.

We have also considered the global modeling potential of the large-scale economic–energy–environmental econometric and interindustry-based Strategic Environmental Assessment System (SEAS) model now in substantial use in the United States in the Department of Energy, the Environmental Protection Agency, and other Federal agencies (House, 1976; House and McLeod, 1977).

While this knowledge of the field does not necessarily make us behave like the farmer rejecting an agricultural innovation because "I already know more than what I know how to use!", our focus here on discussing probable needs of the global modeling user is because we believe this to be the relatively virginal side of the modeling supply–demand equation. Better definition of what is "needed", we believe, will have the salutary effect of encouraging model builders to examine more closely what each has done already (or, with modifications, could do) to meet specific requirements. Meshing the demand for models with their supply has been an interest of the authors, on previous occasions over the years, relative to regional and national models (Steger and Lakshmanan, 1967) and most recently to ecological–environmental modeling (House and Williams, 1979; House et al., 1976). Matters of modeling accuracy and reliability relative to decision-making and strategic-planning needs and methods for increasing modeling utility for public-policy making have been the focus of these previous studies. Increasingly, we have participated in analyses that include aspects and concerns of economics and the energy and environmental resource areas.

1.2 Uses and Users

Here we start from the beginning, i.e. with the identification of classes of potential users and their needs and requirements and the potential applicability of analytic models in meeting these needs. We begin by disagreeing, at least in degree, with the statement of the resident IIASA global modeler Paul Basile that "No client exists for global energy studies. No worldwide decision maker exists . . . . How then can or should the method and results of . . . studies be implemented?" (Basile, 1979). Granted, there is no formal link of the type that Basile indicates, but since when have formal links been of such importance?

We can imagine, literally, thousands of key public and private decision makers, as they did in Business Week's lead article of July 29, 1979 ("World Economic Outlook"), providing the quantitative basis for the country-by-country (traditional) economic indicators, capital spending, gains and losses of developed and less developed countries, energy flows, and changing trade balances, with LINK taking into account both the internal (domestic) econometric relationships and the country-to-country economic relationships as these are influenced directly by trade and indirectly by worldwide levels of output, employment, income, investment, and prices. (This is a biannual feature of Business Week which is repeated in other forms in several economic and business journals.)

Government officials (public-policy analysts and decision makers) around the world are discovering more and more that many of the assumptions that are necessarily treated as exogenous to their national models can be – and many times are – better treated endogenously, as they can only be in multinational (and, ultimately, global) models. Models can convert what are assumptions in national models to policy variables of interest for national-level decision makers.

Increased worldwide awareness of (and sophistication about) the international ramifications of the pursuit of separate national economic objectives has resulted, certainly, from the global modeling related to the Club of Rome. In addition, the Organization for Economic Cooperation and Development (OECD) in its country-by-country reviews of the European economic and environmental outlook (OECD Observer, appearing annually) has utilized international (if not totally global) modeling analyses as "background" for its detailed forecasts. These instances are sufficient – without even looking into the users of SARUM, the MRI model, or Leontief's global model(s) – to illustrate the powerful potential of such efforts.

We wish also to point out that our experience of model builders and model users has seldom resulted in a model use where the user did not want information on sectors other than those over which he exercised some control. We have seen growing interest in the economic or environmental impacts of a decision by an energy-policy maker in order that he should better appreciate the secondary factors that he causes and whether other decision makers' adjustments will attenuate his desired effects. We suggest that the international analogy is obvious and, of course, a prime cause of the supply of global models being high as the demand for such models grows.

Granted, there may be no "worldwide decision maker" (Basile's term) using such models but at the moment, given the state of world political institutions, Basile's statement is only tautological.

We also have another related objection to the following statement by Basile (1979, p. 3):

> "The general purposes of computer modeling may be threefold. First, and perhaps foremost, the real value of models is in the insight, not the numbers, that they provide. Models should be designed for gaining insight and understanding, not (necessarily) for mathematical sophistication; informal "mental models", indeed, are essential prerequisites to formal mathematical models."

Our experience with such models, particularly in policy applications, is that both insights (i.e. trends and directions) and quantitative magnitudes are important to decision making. In an important public-policy analysis concerning the environmental feasibility of the production of synfuel in the United States (US Department of Energy, 1979), residual emission levels relative to acceptable standards for such pollutants had to be compared – admittedly, within ranges set by the uncertainty of specific data – for sets of feasible (to be ascertained) locations.

Many of our analyses cannot address the absolute magnitudes of the total impact but must produce numerical ratios of individual attributions. A global long-term situation for which these factors must be considered is the causes of global concentrations of carbon dioxide that appear to be caused by the growing use of fossil fuels on our planet.

International legal experts evaluating possibilities for reducing (or even preventing) "international offenses against the environment" have raised similar problems concerning problems of quantification:

> "It assumes virtually insurmountable difficulties in the sphere of environmental protection: What type and how much harm is to be covered by the prohibition? How can

such elements of the offense be defined to give adequate notice to those governed thereby? How can one deal with the miniscule individual contribution to a pollution situation which is bad overall? How can rapidly changing national policies be accommodated by such statutes? Perceptions of danger change as rapidly as the use of chemicals and toxicants!" (Mueller, 1979; see also Swan, 1977).

There is a family of applications, all of which demand insights but also much more. These include marginal economic impacts leading to the production of goods by the favored nation, consideration of each region's contribution to global environmental and resource-replacement capacities, and changes in energy supply/demand as unconventional technologies increase to challenge current producers.

1.3 New Interests in Global Modeling

If the United States is typical of the increasing interest in the international ramifications of its economics, technology, and environmental policies, there will undoubtedly be a substantial increase in the attention paid to global models that are capable of treating the interactions between economics, energy, and environmental options and consequences. The Leontief UN model and the SEAS model are illustrative of such systems. Detailed information on sectoral and productive factors for both traditional and "new (high) technology" industries and information about consequences for all factors of production (labor, capital, land, natural and environmental resources, fuel and nonfuel minerals, and "technology") would be very meaningful to the newer international decision-making, policy-analysis, and strategy-formulating agencies. In the United States, these include the International Development Coordinating Agency, the Institute for Scientific and Technological Cooperation, the Overseas Private Investment Corporation, and the relevant AID Bureaus (the first two of these are strictly in the planning stages). The equivalents of these in other OECD nations and the more sophisticated less developed countries, together with the multilateral development banks (e.g. the World Bank) and the UN Development Project, substantially add to the demand for realistic and sound global models with in-depth content sensitive to environment, economics, and energy technology. (To these should be added the growing analytic needs of the UN Association's Center for International Environmental Information and the Institute for Human Settlements.)

In the next section we turn to more specific illustrations of potential applications for global modeling.

2 GLOBAL STAGFLATION AND GLOBAL MODELING

2.1 Characterization of Global Stagflation

Perhaps the major reason for the increased interest in global modeling is the worldwide interest in methods for dealing with inflation, expanding real output, and energy-supply constraints, while at the same time minimizing negative worldwide ecological and environmental effects. In this context, and most recently, the authors have had occasion to become more aware of and involved with the developing and expanding official interest in the United States and other developed countries in the worldwide ramifications of the staggering global stagflation. The following points seem to summarize an increasing consensus about the characteristics of this unusual, pervasive, and structural phenomenon as it applies to the economic structure of the nations of the western world (from Steger, 1979).

(1) First of all there is the characteristic of longevity. Most observers agree that the current levels of stagflation have been "in the making" for many years, probably decades. Recent analyses have shown that in the 1970s the economic system of the United States appears to have reached the "rule of 6–6"*. This "rule" holds that the economy will not – indeed, cannot – experience unemployment or inflation in any combination less than 6% inflation and 6% unemployment (earlier analyses of structural changes, in the 1950s and mid-1960s, were performed by Drs. B. Okun and A. Packer). Tracing of the inflation–unemployment experience since World War II reveals how the economy has moved from a 4–4 and a 4–5 to a 5–5 rule during the late 1960s and early 1970s. The long-term nature of this worsening economic position does not negate the possibility that a fairly abrupt change in the world economy occurred in 1973. No one doubts that the long-standing fundamental trends have worsened and that basic solutions need to be found, solutions which transcend the so-called "energy" or "food" crises popularized in recent years. (We recognize of course that both the energy and food problems have long-term antecedents also.)

(2) A second characteristic of stagflation problems is that they are global not national. The several "crises" pose considerably more direct problems for the European nations than for the United States; the developing countries both affect and are affected, considerably, by world stagflation. Any solutions which are purely national in nature and which do not comprehend the effects on other nations, and further rounds of international feedback, may not only fail but may in fact do permanent harm to the situation.

(3) A third characteristic of the problem space is that many economic sectors are contributing, to an extent, to the worsening stagflation. Steel, nonfuel minerals, freight transportation, automobiles, and the finance industries, to name a few, have from time to time been the focus of public attention. The question whether increased government intervention – be it protectionism, bail-out, or other forms of assistance – was warranted in these instances has not necessarily reached the crisis stage as it has done for energy and food; nevertheless, erratic performance, investment, profit, and employment in these and other sectors have been factors in feeding stagflation. Broad-scale economic solutions must meaningfully deal with all these key sectors, not merely in reversing trends but also in identifying appropriate roles for each which can help to make them partners in the recovery efforts.

(4) Fourth, and consistent with the concept that many sectors need to be involved, is the characteristic of stagflation which affects all factors of production. Private investment is often singled out as a primary victim or, in some cases, a leading culprit; however, other productive factors are no less "responsible" and/or victimized. Labor's productivity

* Courtesy of Dr. Ronald Kramer, US Department of Commerce.

is a leading "cause and/or effect", depending on the stagflation expert, and no doubt is caught up in the cycle. Management, as well as capital ownership generally, has risk-aversion tendencies which become more pronounced. Landowners both benefit from the inflation and make it more difficult to perform simple and traditional land assembly and industrial siting functions. Solutions to stagflation need to find an appropriate and rewarding role for each of the productive-factor groupings.

To sum up, we have a consensus that stagflation is a long-term worldwide situation across most economic sectors and is being affected by and is affecting all factors of production. It is a truly pervasive structural problem that cannot be solved simply by studying its parts, which in this case are nations and, often, multinational corporations.

2.2 Global Stagflation Initiatives

The ingredients of appropriate solutions to stagflation must somehow be tied to this characterization. At the time of writing, these ingredients would seem to be characteristics of an overall solution to stagflation, the complexity of which practically *begs* for sophisticated global analysis.

(1) *Global.* To match the global reach of stagflation its "cure" needs to be promoted through an internationally coordinated approach. This approach need not necessarily be overly detailed or comprehensive planning but rather a push in what are obvious "right directions" to increase simultaneously employment, productivity, and investment and to moderate inflation. The approach must recognize the relationships between the United States, the OECD nations, and the developing countries, in terms of both trade and immigration.

(2) *"Key" sectors.* To match further the global nature of stagflation, the solution space needs to include mechanisms which encourage massive private investment in high-productivity "key sectors" where increased output will produce the most substantial moderation of inflation. This is where investment in potentially high-technology energy industries (heavy oils, tar sands, shale oil, unconventional gases, centralized solar, synthetic fuels, decentralized photovoltaics, and nuclear reprocessing and waste disposal) might make the most global sense in terms of increased advanced-technology exports together with simultaneous reduction of global energy problems.

(3) *Creating nation-by-nation winners.* By high-productivity "key sectors" we mean that the developed countries would, by and large, adopt a coordinated development strategy most characterized by the Japanese selection process. Simply put, the Japanese appear able to pick "winners" in the economic sweepstakes: they encourage these winners as they phase out industries that are under severe competitive pressure. A global antistagnation strategy would be somewhat different in that each nation, taken separately and then together with other nations, would be creating winners that were best suited to its own comparative advantage rather than imitating or trying to obtain benefits from winners established elsewhere. For analogies it would be interesting to examine the post-war experience of the advanced economies in developing high-technology export products. Foremost on that list might be nuclear reactors, consumer equipment, executive aircraft, computers, prefab construction, and microelectronics. In the future, a number of high-technology energy, food, health, education, pollution-control, and sophisticated

manufacturing industries could be added to this list of winners. These products have not normally been generated by the free market completely unaided. Initial development has generally been supported by substantial government expenditure and other public aid. In many cases of course this expenditure was not directed towards the ultimate products but had other objectives such as defense or space exploration. National choice of winners implies national fiscal and marketing support to initiate the boom.

(4) *The maturing industries*. Steel, automobiles, textiles, and traditional manufacturing would be weaned away from government assistance, except as this might be agreed on for short-run equity and social reasons. We are only now beginning to recognize the strengths and weaknesses in capitalist-world technology and what can be done to reduce "technology gaps" between the United States and other developed nations.

(5) *The developing nations*. Further internal developments in the less developed nations would be encouraged by this strategy. This would be especially true if that development were to take the form of reducing pressures on scarce world supplies such as energy and food or reducing the cost of providing essential services such as health and education. Large-scale investment of private funds with government support would be encouraged to avoid the need to increase government expenditures. Such investment would help the United States and other countries to reduce their federal budget deficits, an issue with high political visibility throughout the world. The most advantageous situation would be to use stocks of funds held by such countries as Saudi Arabia, Kuwait, the Federal Republic of Germany, and Japan. It would clearly be less inflationary if these funds were used to finance productive investment than if they are allowed to fuel speculative booms in land, housing, and commodities.

(6) *Other factors of production*. All factors of production, and not merely private investment capital, play a role in the solution of stagflation. Labor in high-technology countries would require and would receive expensive sophisticated training and would be rewarded with high-wage jobs. High-technology-importing nations, specializing in medium and low technology and investment in more conventional industries, would increase their lower-wage jobs and would almost certainly be better off than under continued stagflation, high unemployment, and eroding real wages. Furthermore, on the wages and jobs front, there would be less attention paid to intranational regional disparities and more encouragement of worker mobility to places of the highest productivity and labor need.

(7) *Importing or exporting environmental pollution*. A concern only in recent years in the developing nations (Mayur, 1979; Bassow, 1979) and in the advanced-technology developed countries, interactions between national (domestic) economic policy and international environmental implications are becoming increasingly recognized as an important part of the problem solution (OECD, 1979). In the advanced nations (the OECD and Yugoslavia) in fact a declaration was reached which recognized "the need to integrate environmental, economic, and social policies . . . to ensure that environmental considerations are incorporated at an early stage of any decision in all economic and social sectors likely to have significant environmental consequences . . . (including the development of) systems to account for changes in environmental quality and related stocks – and the continuation of cooperation, both bilaterally and through appropriate international organizations, with *all* countries, in particular developing countries, in order to assist in preventing environmental deterioration" (OECD, 1979).

2.3 Energy–Environment–Economic Tradeoffs: Synfuels as an Illustration

Much of the concern of this conference is on the environmental and ecological aspects of global modeling. The most obvious of the interrelationships to reflect is of course the physical diffusion or "export" of environmental residuals, caused by production and/or consumption in one country, from that country to another. Among such diffusion problems leading to potentially dangerous health problems are the disputed effects of chlorofluorocarbons (CFCs) on the atmosphere. Based on studies completed over the past five years, CFCs released from aerosol containers (and other sources) diffuse into the upper stratosphere; there the liberated chlorine can react with the ozone, reducing its ability to screen us protectively from ultraviolet radiation. Another atmospheric problem is that of acid rains. The combustion of fossil fuels leads to sulfur and nitrogen compounds being carried considerable distances in the air and then being returned to earth as rain or snow with provably adverse effects on agricultural and forest output and freshwater fish, depleting effects on soil nutrients and aquatic ecosystems, and corrosive effects on materials. Still another problem is the international protection of water quality as it is affected across national boundaries.

Physical (diffusion) effects have received the most public attention from among international environmental experts. Economists, however, have posed a host of other effects which are much less tangible but involve the indirect import and/or export of residuals flowing, simply, from production and consumption actions within each nation (Van Zele, 1978). Many of these "nondirectly physical" externalities arise from uncoordinated national decision making about research and development on energy technology, subsequent national investment strategies, and how environmental standards are developed and enforced – nation to nation – in the light of changing world energy patterns and policies. These are not necessarily "hostile" actions on the part of the pollution-exporting nations. More frequently than not it is primarily an unknowing action, the indirect effects (through secondary and even more indirect rounds) of which are "externalities" not obvious to the originator! Examples of such indirect externalities include activities related to both public and private policies such as the environmental analysis of synthetic liquid fuels (synfuels). The international and national ramifications of worldwide extraction and production patterns for CO_2, NO_x, SO_2, and particulates as well as more localized, regionally induced, and secondary environmental-quality impacts on air, water, hazardous waste, toxics, and visibility are among those international externalities which will flow from global decision making about synfuel investment, extraction, production, and use patterns. Existing analyses of the environmental impacts of alternative synfuel options, referred to in the foregoing, were purely national in geographic scope. The analytic models and data bases of the US Department of Energy do not generally allow an examination of international consequences: unanticipated indirect environmental effects *could* affect other nations depending on the technology of the particular synfuel selected, which coal supplies are used, the degree to which production takes place in the United States or elsewhere (e.g. the United Kingdom, South Africa), how the synfuel product is transported and used, and many other factors.

We have not examined other global models from this standpoint but it is likely that the best systems for studying the world consequences of synfuel options will be the Leontief UN input–output model and/or an expanded SEAS modeling system. (For the reader who is not familiar with the SEAS system and its associated data bases we have attached a short description in Appendix 1.) The Wharton Project LINK system, modified for the occasion, would seem to be ideal as the front-end economic model. Apparently, extensive data bases have been developed in Project LINK to support the construction of econometric models of other economies. (Owing to data limitations these models have usually been constructed on the basis of an annual time period, and therefore the corresponding data bases have almost invariably contained annual data.) In the current operational versions of LINK, models of both Mexico and Brazil are presently used in the preparation of regular interindustry economic (conditional) forecasts. These models are supported by annual data bases containing 1000 and 400 variables respectively. In addition, data bases have been assembled for the construction of models of Puerto Rico, Panama, Chile, and Venezuela. (Previous work has also resulted in the assembly of a data base containing 3000 variables relating to the economy of the Soviet Union.)

2.4 The Introduction of New Energy Technologies: Employment and Environmental Dynamics

Another commonly raised set of questions, which is difficult to analyze using current global models, concerns the degree to which dynamic employment and environmental consequences flow from the introduction of a variety of energy technologies, perceived by each nation to be most beneficial relative to its own national economy. For the United States, for example, such a list could well look like Table 1. These energy sectors are "new" in the sense that they are not typically included in the traditional national econometric and/or input–output models. (In the United States these technologies (and their technological coefficients) are being incorporated into the large-scale Bureau of Labor Statistics input–output model (see US Bureau of Labor Statistics, Office of Economic Growth (1978) and CONSAD Research Corporation (1979)).)

The primary disadvantage of the traditional overall macroapproach is that one cannot obtain from it the dynamic direct and indirect employment, and ensuing environmental, impacts of introducing a quad* of one energy technology versus another. These unit impacts are also of key interest from a policy point of view in order to compare employment and pollution-control requirements against other factors related to these sectors. Thus as an addition to the current global modeling analysis we suggest that additional types of analyses be performed with the data currently being developed jointly by the US Department of Energy and the US Department of Labor as well as in the SEAS effort. This section outlines a framework within which these two distinct types of analyses can be carried out.

The starting point of our revised macroanalysis would be a scenario developed from an existing large-scale input–output model (such as a global "BLS"** model) that implied certain broad assumptions regarding overall energy use in the economy and its mix by fuel type. In this regard, while the BLS model focuses on the dollar transactions between the energy sector and other sectors of the economy, implicit British thermal unit (Btu) to

* 1 quad = 10^{15} Btu = 1.055×10^{18} joules.

** BLS = Bureau of Labor Statistics.

TABLE 1 Preliminary list of "new" US energy sectors.

Coal	*Electric utilities*
1 Eastern underground mining	1 Coal
2 Eastern surface mining	2 Oil
3 Western underground mining	3 Gas
4 Western surface mining	4 Hydropower
	5 Wind
Nuclear	
1 Fuel extraction and preparation	*Residential sector*
2 Power generation	1 Decentralized photovoltaics
3 Waste disposal and reprocessing	2 Hot-water heating
Synthetic fuels from coal	
1 High-Btu gasification	

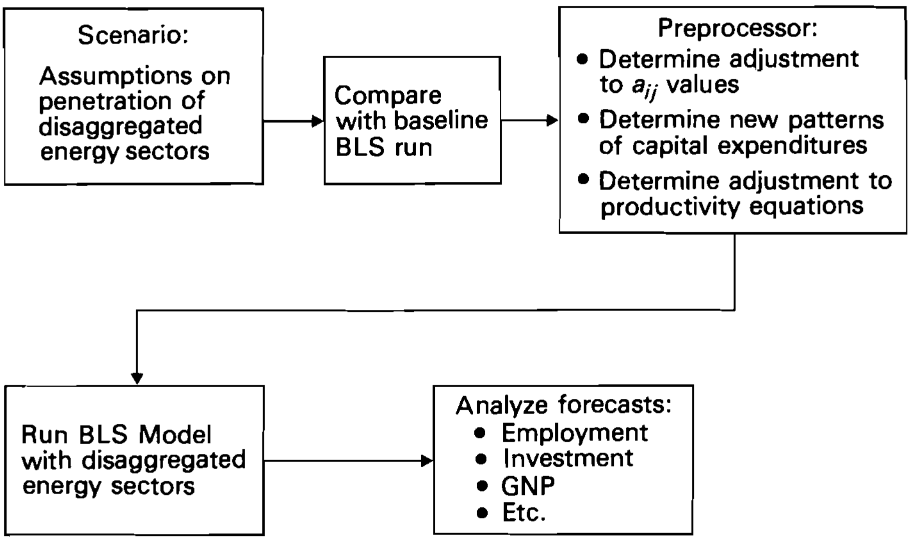


FIGURE 1 Employment impacts of disaggregated energy sectors with the BLS model.

dollar conversion factors are available to enable the user to estimate the Btu forecast implicit in the input–output forecasts.

Using this as a starting point one could introduce the new disaggregated sectors and could recompute the forecast based on alternative assumptions regarding their projected use. Several examples are as follows.

(1) One could change the mix of type of coal mining. The existing model has one coal-mining sector. One could vary the mix of the four coal sectors and could recompute employment and other forecasts.

(2) One could change the mix of type of electric utilities.

(3) One could shift to coal gasification.

(4) One could increase the use of solar energy in residential facilities.

The calculations with these sectors would involve using the input–output (capital and *A* matrix) coefficients developed earlier, together with projected levels of output and capital expenditures. The output forecasts are generated endogenously in the model but adjustments to the input–output coefficients would need to be made to account for the shift from one technology to another (e.g. gas-fired to coal-fired utilities, natural gas to gasified coal). Capital expenditures could be generated in a "preprocessor" run prior to the model that would take the supply forecasts and convert these to capital expenditures using the unit-cost and "phasing" data developed for this study.

Estimates on the number of years required to construct various energy facilities are provided in the Bechtel and other data bases. These estimates also indicate the portion of construction activity and in turn the level of capital investment which will occur in each year of the construction cycle. To incorporate these estimates into a run of the BLS model, information is required on depreciation or replacement rates for various capital structures and equipment. Figure 1 depicts the previous discussion relative to modifications to the BLS model to assess the employment impacts of disaggregated energy sectors. In Appendix 2 this procedure is described in mathematical terms.

2.5 Other Global Modeling Issues

We can only refer briefly to a few additional issues which are important in global matters but which are for the most part excluded from most global models. Examples include the following.

(1) *The behavior of multinationals*. Many economic consequences flow from little understood actions of multinationals. There are a number of microsimulation models (e.g. Brookings, the US Treasury Department) which could be used in side analyses; particularly in the case of the very large energy corporations, the omission of behavioral considerations is very unrealistic and makes it difficult to study different (national and international) incentives and sanction structures.

(2) *Game aspects*. Intelligent self-seeking national behavior, e.g. the exportation of specific pollutant residuals, can best be studied through application of the theory of games. No global analysis model that is realistic enough to be used in policy analysis currently includes such aspects; methods for considering such dynamic "gaming" behavior, even if not included endogenously within a global model system, would be most helpful.

(3) *Regulatory/incentives aspects*. There is much interest in the effects of economic deregulation and more market-oriented incentives to promote good environmental practice. No existing global analysis model has sufficient detail to study alternative regulatory/incentives arrangements, for example, encouraging the development and production of renewable energy technologies.

3 CONCLUDING REMARKS

It would be useful to make preliminary, albeit crude, analytic investigations, using combinations of labor/energy-technology/manpower projection models (based on adaptations of the BLS Economic Growth Model and the SEAS) and international (world) econometric models such as Project LINK, to make the following types of "ball-park" computations.

(1) For each billion dollars of selected (successful) energy research and development, what will happen to the following: jobs, here and elsewhere; exports, imports, and the balance of payments; wage levels; prices; unemployment; and, ultimately, economic, energy-use, and environmental tradeoffs?

(2) Other computations could be made to estimate what types of public initiatives and support would be most cost-effective in promoting successive levels of private investment, of various degrees of risk, in each of the developing and/or the developed nations.

We believe that it would be useful to have some demonstrated illustration of the use of global models to study interesting, perhaps important, environmental/energy/-economic policy issues. Perhaps the six-year-old environmental cooperation agreement between the United States and the Soviet Union could be used as the basis for such a study monitored by IIASA: in any case, we believe there *are* many potential users for a wide variety of global modeling analyses.

APPENDIX 1 SEAS: Energy-Technology and Labor-Impact Modifications

SEAS (Strategic Environmental Assessment System) was developed by the Office of the Assistant Secretary for Environment, the Department of Energy, and the Environmental Protection Agency. It is a system of models whose primary purpose is to evaluate the national and regional environmental implications of alternative energy and economic scenarios. A flow diagram of the system is given in Figure A1.1. The core of the economic component of the system is a modified version of the Almon and Nyhus INFORUM input–output model. One modification made to the original version of INFORUM was to replace the forecasts of capital expenditure for the energy sectors in the original model. The list of sectors for which investment calculations are made is specified in Table A1.1. The data base on unit capital cost and capital vectors is drawn primarily from the Bechtel work as well as that of the Solar Energy Research Institute.

The method for undertaking the investment calculations is straightforward. The scenario assumptions used in this system regarding levels of energy demand and energy-technology development (coal gasification, fluidized bed, etc.) are first entered in the system in a module called the Energy System Network Simulator. This network traces the flow of energy from primary-resource extraction through transportation and conversion to end-use demand (measured in units of 10^{12} Btu). The time path of these flows for individual technologies is one critical factor in determining investment levels. Other key variables include (1) unit costs (millions of US dollars per 10^{12} Btu of output) for each energy technology, (2) number of years it takes to construct a facility, (3) the percentage phasing of costs over the construction period, and (4) the depreciation of existing facilities over time.

The investment calculations work in an anticipatory fashion. The time paths of Btu flows for a given facility type (e.g. nuclear light-water reactors) serve as targets for which capital resources must be set aside; i.e. construction of a plant takes time (as much as 9–10 years in some instances) and for a supply technology to provide a certain level of

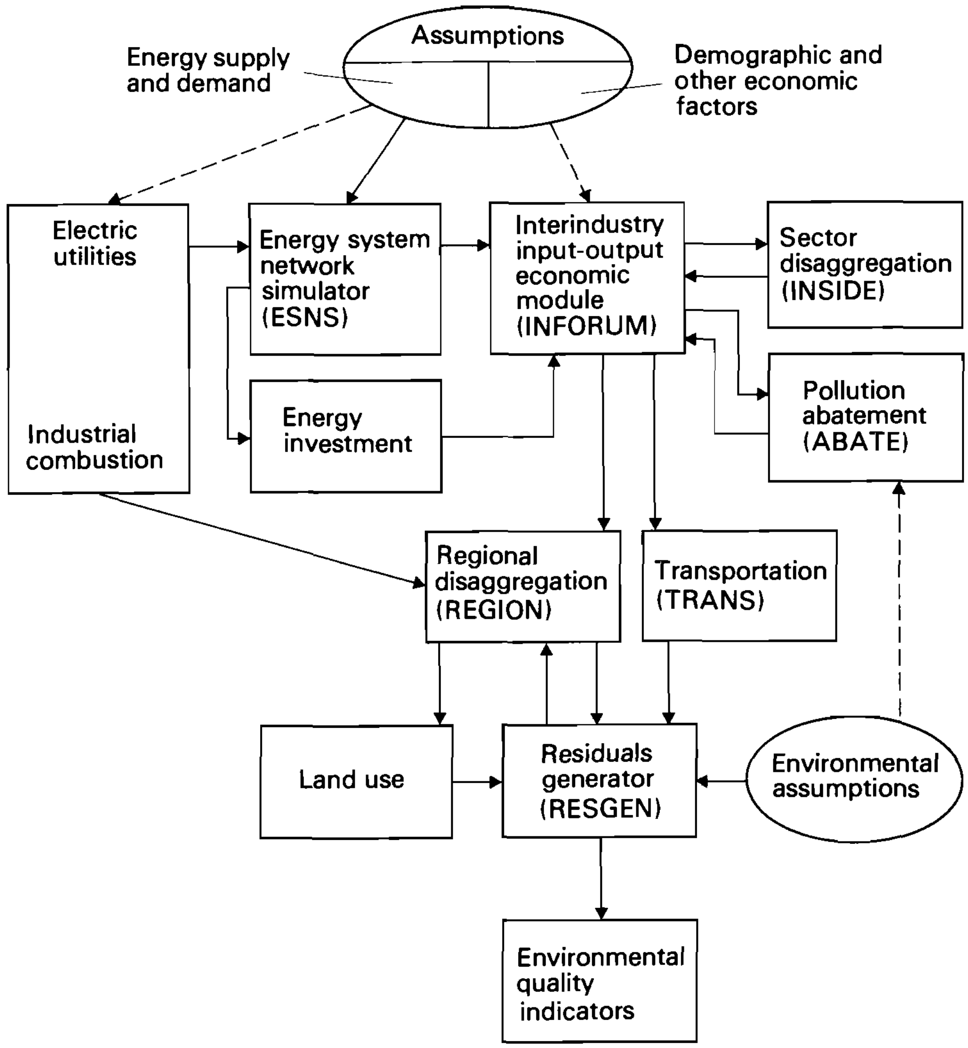


FIGURE A1.1 A block diagram of SEAS.

output in given years new plants are built over a prior period. The capital cost and phasing of resource requirements are determined up to the year 2000 using the model. These requirements define a "bill of goods" added to other final-demand components and entering into the input–output solution.

In addition to doing these calculations for major scenarios, a procedure has been developed that allows SEAS users to estimate the indirect environmental and employment impacts from constructing and operating any of the energy facilities in Table A1.1 at a unit level (defined as an output of 10^{12} Btu). The procedure is essentially to consider the incremental requirements of the products of each of the 2000 INFORUM sectors that are directly needed to construct each facility, to convert this to *total* impacts on sectoral

TABLE A1.1 List of sectors in the investment module[a].

Nuclear cycle – surface mines	Electric utilities – combined cycle
Nuclear cycle – underground mines	Electric utilities – fluidized bed
Nuclear cycle – milling	Electric utilities – coal (steam)
Nuclear cycle – conversion	Electric utilities – gas (steam)
Nuclear cycle – enrichment	Electric utilities – liquid-metal fast-breeder reactor
Nuclear cycle – fuel fabrication	Electric utilities – light-water reactor
Nuclear cycle – reprocessing	Electric utilities – geothermal
Nuclear cycle – waste disposal	Electric utilities – hydroelectric
Oil cycle – onshore oil (primary)	Electric utilities – transmission
Oil cycle – onshore oil (enhanced)	Electric utilities – distribution
Oil cycle – offshore oil	SHACOB active
Oil cycle – Alaskan oil	SHACOB passive
Gas cycle – onshore gas	Residential photovoltaic
Gas cycle – offshore gas	Centralized photovoltaic
Gas cycle – Alaskan gas	Solar thermal
Coal cycle – mining (eastern underground)	Wind-energy conversion system
Coal cycle – mining (eastern surface)	AIPH: parabolic dish
Coal cycle – mining (western underground)	AIPH: parabolic trough
Coal cycle – mining (western surface)	AIPH: flat plate
Coal cycle – coal-preparation plants	Biomass farm
Synfuels – H-coal	Agriculture and forestry residue collection
Synfuels – methanol	Biomass electric
Synfuels – high-Btu gas	Manure residue gasification
Synfuels – low-Btu gas	Agriculture/wood gasification
Synfuels – shale oil (surface)	Biomass residential
Synfuels – shale oil (in site)	Municipal waste electric
Geothermal cycle – geothermal direct	

[a] Abbreviations: SHACOB, solar heating and cooling of buildings; AIPH, agricultural and industrial process heat.

output, and finally to translate the output impacts to employment using forecast productivity (defined as output per employee) levels for each sector:

$$L = P(I - A)^{-1}Y$$

where Y is a final-demand vector representing resource requirements to construct (or operate) 1×10^{12} Btu of a facility and P is a matrix with the inverse of output per employee by sector as the diagonal element. The sum of the elements in L will give the total employment impact associated with constructing the given facility. (An equation similar to the one shown is used for environmental impact, using a residuals coefficient matrix instead of P.)

APPENDIX 2 Modification of the BLS Model to Assess Employment Impacts of Disaggregated Energy Sectors

Let us define an economy in dynamic equilibrium for the years $t = 1, 2, \ldots, n, n+1, n+2, \ldots, p, p+1, p+2, \ldots$. In addition, let us suppose that the following system of input–output matrices adequately describes this equilibrium for $t = 1, 2, \ldots, p$.

The current transactions and capital flows may be described respectively by

$$X_t - Y_t = A_t X_t = m_t \quad (t = 1, 2, \ldots, p) \tag{1}$$

$$K_t \quad (t = 1, 2, \ldots, p) \tag{2}$$

The capital-goods component of Y_t is the row sum k_t of K_t. The labor requirements are

$$L_t = r_t^{\mathrm{T}}(1 - A_t)^{-1} \tag{3}$$

Suppose that, through an exogenous decision, the dynamic equilibrium and labor requirement described in eqns. (1)–(3) were to be changed by the introduction of a new energy technology or mix of supplies in year n with construction commencing in year 1. Commencing in year n, eqns. (1), (2), and (3) would be replaced by equations whose matrices contained one additional dimension:

$$\bar{X} - \bar{Y} = \overline{A_t X_t} = \bar{m}_t \quad (t = n, n+1, \ldots, p) \tag{$\bar{1}$}$$

$$\bar{K}_t \quad (t = n, n+1, \ldots, p) \tag{$\bar{2}$}$$

$$\bar{L}_t = r_t^{\mathrm{T}}(1 - \bar{A}_t)^{-1} Y_t \quad (t = n, n+1, \ldots, p) \tag{$\bar{3}$}$$

A comparison of eqns. (3) and ($\bar{3}$) yields the employment impacts of the new technology for the years $t = n, n + 1, \ldots, p$.

In addition to these employment impacts there will also be employment impacts over the construction phase of the disaggregated energy sectors. Essentially, if construction commences in year 1 and comes on line in the year n, K_t $(t = 1, 2, \ldots, n)$ is replaced by $\bar{K}_t$ $(t = 1, 2, \ldots, n)$, Y_t over this period is altered by $\Delta Y_t = \bar{k}_t - k_t$, and the employment impacts for $t = 1, 2, \ldots, n$ may be estimated by

$$\Delta L_t = r_t^{\mathrm{T}}(1 - A_t)^{-1} \Delta Y_t \quad (t = 1, 2, \ldots, n) \tag{$\bar{4}$}$$

This estimate will contain measurement errors that go beyond those that are present when comparing eqns. (3) and ($\bar{3}$) for $t = n, n + 1, \ldots, p$. The errors present when comparing eqns. (3) and ($\bar{3}$) are errors that are always present because we cannot perfectly measure economic variables (and because model assumptions are too rigorous). The errors present in eqn. ($\bar{4}$) are errors of omission and have two sources: ΔY_t and A_t for $t = 1, 2, \ldots, n$.

A2.1 Errors of Omission Present in $\Delta Y_t = \bar{k}_t - k_t$

There are three sources of the differences between $\bar{k}_t$ and k_t: (a) increased capital purchases (equipment, structures, and inventories) originating in the new energy sector, (b) decreased capital purchases originating in the partially displaced energy sectors, and (c) increased and decreased purchases originating in the other energy sectors owing to changes in relative prices. Source (c) will probably not be estimable owing to resource and data constraints, and this will be a source of error in ΔY_t ($t = 1, 2, \ldots, n$) and will create an error in the employment impacts computed with it. The sign of this error cannot be determined a priori, but it will probably be positive (negative) if $\bar{k}_t > k_t$ ($\bar{k}_t < k_t$); $\bar{k}_t > k_t$ implies that the new energy sector is more capital intensive (capital per Btu of capacity) than the displaced sector. Since investment is limited by savings and external borrowing it is likely that on a net basis investment in all other sectors combined will be lower if the new energy sector absorbs more capital than the displaced energy sector.

Also, to the extent that the rebalancing procedure used to obtain eqn. ($\bar{1}$) for $t = n, n+1, \ldots, p$ does not adequately capture the impact of item (c), this error is also present in the comparison of eqns. (3) and ($\bar{3}$). If the capital elements (structures, equipment, and net inventory change) of $\bar{Y}_t$ significantly exceed those in Y_t for $t = n, n+1, \ldots, p$, then there is no reason to believe that error of this kind is present.

A2.2 Errors of Omission Present in A_t ($t = 1, 2, \ldots, n$)

If the A_t matrices used to form the inverses in eqn. ($\bar{4}$) are the same as those used in eqn. (1) then some additional error will be present. The interindustry flows represented by A_t in eqn. (1) do not take into consideration the impacts of the change in investment (ΔY_t) on relative prices and nonenergy-related final and intermediate purchases. The sign of this error cannot be determined a priori.

A2.3 Analysis of Employment Impacts – Unit Impacts

The foregoing steps essentially include the framework for obtaining a direct and indirect employment impact on a per quad basis. The construction-related employment impacts would be determined by eqn. ($\bar{4}$) except the ΔY_t vector would represent only the *additional* capital requirements for constructing enough facilities to produce a quad of energy. To this could be added the direct operating labor. This would be directly taken from the data base on operating labor (and adjusted for production workers and productivity changes where needed). The final component of employment impact relates to indirect employment generated from the purchase of operating materials. This is estimated by determining the bill of goods of operating materials (B_t) needed to supply one quad and computing the following:

$$L_t^* = r_t^{\mathrm{T}}(1 - A_t)^{-1} B_t$$

It should be emphasized that while this analysis of per quad employment impacts enables useful comparisons across technologies it is not a substitute for the macroforecasts. In the latter, overall adjustments and rebalancing in the economy, which are missed in the analysis of unit impacts, are being considered.

REFERENCES

Basile, P.S. (1979). Energy modeling for the long-term – and with a global perspective. Options, IIASA, 1.

Bassow, W. (1979). The Third World: changing attitudes toward environmental practices. AAPSS Annals, 444: 112–120.

Bruckmann, G. (Editor) (1978). SARUM and MRI: Description and Comparisons of a World Model and a National Model. IIASA Proceedings Series, Vol. 2. Pergamon, Oxford.

CONSAD Research Corporation (1979). Working paper on energy employment analysis: recommended data sets and procedures. Prepared for US Departments of Labor and Energy.

House, P. (1976). Trading off environment, economics, and energy: a case study of the EPA's Strategic Environmental Assessment System (SEAS). Draft. University of California Institute of Transportation and Traffic Engineering, Berkeley, California.

House, P. and McLeod, J. (1977). Large-scale Models for Policy Evaluation. Wiley, New York.

House, P., Patterson, P., and Williams, E. (1976). Policy making with divergent forecasts: a case for data consistency in federal decision making. Report for National Commission on Supplies and Shortages. University of California Institute of Transportation and Traffic Engineering, Berkeley, California.

House, P. and Williams, T. (1979). On the Efficacy of Mousetraps: A Case Study of the Use of Models to Refine Environmental Emission Standards. Office of the Assistant Secretary for Environment, US Department of Energy, Washington, D.C.

Mayur, R. (1979). Environmental problems of developing countries. AAPSS Annals, 444: 89–101.

Mueller, G.O.W. (1979). Offenses against the environment and their prevention: an international appraisal. AAPSS Annals, 444:58.

OECD (1979). Prevention less costly than cure: main theme for OECD's environment ministers. OECD Observer, May: 9–13.

Peterson, J.M. (1979). Global and regional implications of the social costs of environmental pollution. Journal of Regional Science, Spring: 68–75.

Steger, W.A. (1979). Designing an international high-technology investment program: an alternative to global stagflation. CONSAD Research Corporation, Pittsburgh, Pennsylvania.

Steger, W.A. and Lakshmanan, T.R. (1967). Plan evaluation methodologies: some aspects of decision requirements and analytical response. Paper prepared for Highway Research Board Conference on Urban Development Models.

Swan, J. (1977). Legislation and human settlement. In P. Laconte (Editor), The Environment of Human Settlements, Vol. 1. Pergamon, Oxford.

US Bureau of Labor Statistics, Office of Economic Growth (1978). The Potential Economic Growth Assessment for the US Economy (PEGASUS). US Bureau of Labor Statistics, Office of Economic Growth, Washington, D.C.

US Department of Energy (1979). Environmental Analysis of Synthetic Liquid Fuels. US Department of Energy, Washington, D.C.

Van Zele, R.L. (1978). An international (interjurisdictional) analytical framework for environmental management. Cornell University Regional Science Dissertation and Monograph Series, No. 7. Cornell University Press, New York.

DISCUSSION

In reply to two questions by Snower, Steger *expressed the opinion that industrial development will most probably be held up more by technological constraints than by environmental ones. This view is rather new. The mere handling of solid waste (e.g. in connection with the deployment of oil shale) will pose grave problems. As to the second question,* Steger *clarified that the implementation of any kind of synthetic-fuel program would not lead to a major contribution from that side for quite some time to come simply because the use of fossil fuels would also continue to grow.*

Faber *asked about the assumptions underlying the projected decline of the US share of energy consumption from 27% to 8%.* Steger *stated that these data were taken from work done by the Oak Ridge National Laboratory, assuming a doubling of US consumption and a nearly tenfold increase elsewhere in the world.* Mesarovic *added that part of this change will simply be attributable to population increases.*

Meier *expressed the view that, in the field of energy, global modeling has so far tended to neglect technological advances between which to choose.* Steger *agreed that it should be a major purpose of the models to investigate alternative options and their impacts.*

THE QUANTIFICATION OF ENVIRONMENTAL STRESS USING THE SARUM-AREAM MODEL*

J.M. Mula and K.T. Parker**
Department of Science and the Environment, Lombard House, Canberra, A.C.T. (Australia)

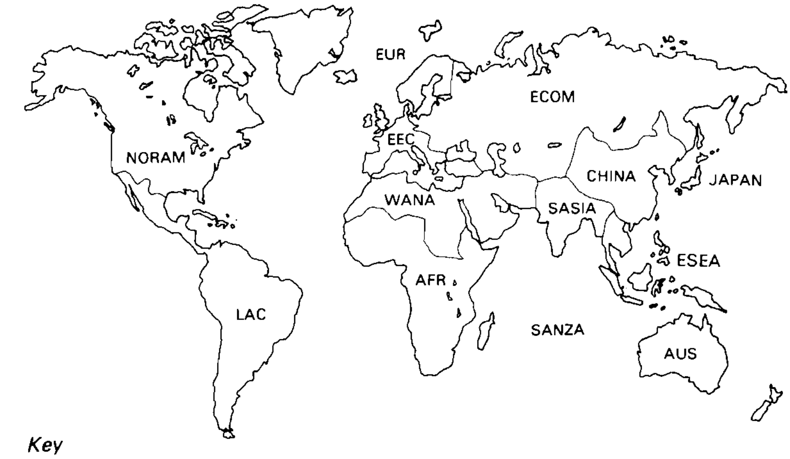
1 INTRODUCTION

In this paper we discuss how a large-scale economic model can be used to assess environmental stresses. The model used for these studies is the Systems Analysis Research Unit Model (SARUM), the global model developed by the Systems Analysis Research Unit of the Department of the Environment in the United Kingdom (UK). SARUM has been described in detail elsewhere (Department of the Environment, Department of Transport, 1977; Parker and Raftery, 1978; Wagstaff, 1979) and was also presented to the Fourth IIASA Global Modeling Conference (Bruckmann, 1978). It has most recently been used by the Organization for Economic Cooperation and Development (OECD) Interfutures project to investigate relations between developed and less developed countries (OECD, 1979). SARUM is also currently being used by the Commission for the Future in New Zealand to investigate possible future roles for New Zealand in the world. These uses of the model are only concerned with economic and natural-resource aspects of possible world futures; the extensions which will incorporate an environmental submodel are being carried out by the Department of Science and the Environment in Canberra as part of their Australian Resources and Environmental Assessment (AREA) Project.

The AREA Model (AREAM) has taken the SARU regionalization of the world used for the Interfutures project and within the 12 regions has two new regions for Australia and New Zealand (the European Economic Community (EEC) and Western Europe have also grouped as one region and South Africa has been grouped into Africa) (see Figure 1). Two additions to SARUM that will be made are population and environment submodels; the latter submodel is the subject of this paper. For population it is hoped to replace the present exogenous UN projections with an endogenous demographic mechanism for the

* The views expressed in this paper do not necessarily reflect the opinions of the Department of Science and the Environment, nor of the Australian Government.
** On secondment from the Department of the Environment, London, UK.

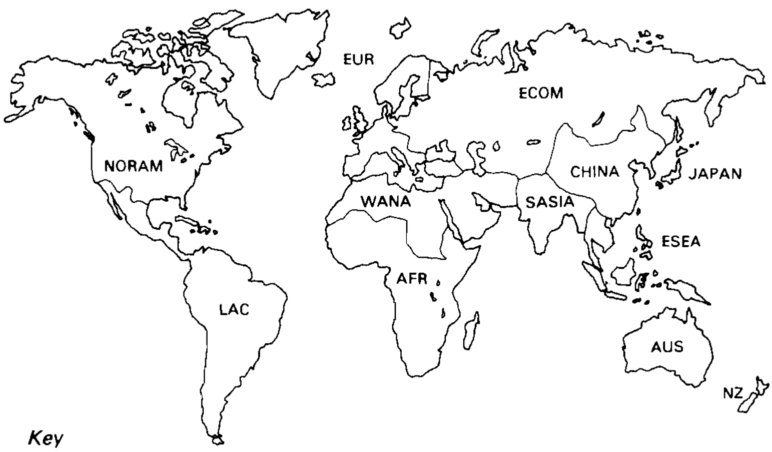
(a)



Key

NORAM	United States, Canada	LAC	Latin America, Caribbean
JAPAN	Japan	SASIA	South Asia
SANZA	South Africa, Australia, New Zealand	ESEA	East and Southeast Asia, Oceania
EEC	European Community	CHINA	China
ECOM	European and Asian COMECON	WANA	West and North Africa
EUR	Other Europe, Asia Minor	AFR	Other Africa

(b)



Key

NORAM	United States, Canada	LAC	Latin America, Caribbean
JAPAN	Japan	SASIA	South Asia
AUS	Australia	ESEA	East and Southeast Asia, Oceania
NZ	New Zealand	CHINA	China
ECOM	European and Asian COMECON	WANA	West and North Africa
EUR	Other Europe, Asia Minor	AFR	Other Africa

FIGURE 1 (a) Regions for SARUM projections; (b) regions for AREAM projections.

Australian and New Zealand regions based on modeling work that has already been carried out in Australia. Migration will also be modeled using a mechanism similar to that developed for trade – a migration bias matrix. Together with the environment submodel, the impact on the Australian environment and natural resources of economic conditions and demographic change worldwide will be monitored and assessed. The AREA Project itself is in fact a pilot study to measure the utility of using models of this nature for prospective analysis within the government policy framework.

2 THE ENVIRONMENT SUBMODEL

The study of the interrelationships between the economy and the environment spans such a wide range that it is impossible for one model to provide a comprehensive coverage. It is always essential when using a particular model to tackle problems to which the model is well suited; different areas of study will require different approaches. A first useful step in narrowing down the study area is to distinguish between environmental stress and environmental impact or response. Stress relates to human activity which affects the environment whereas the consequential effects on the environment and the ways in which it responds are referred to by the term environmental impact. For example, the emission of sulfur dioxide from a coal-burning power station is an environmental stress but the effect on river fish of the resulting sulfuric acid in the rain is an impact. Ultimately, interest will focus on the response of the environment; it is the deleterious impacts which are to be avoided, or to be borne for the sake of some greater advantage. Stresses which are part of an ecological equilibrium do not usually give rise to great concern; for example, the activities of hunter–gatherer societies. This classification of stress and response is used by the Australian Environmental Statistics Project (AESOP) (Friend, 1978).

The analysis of environmental impact involves many branches of science such as meteorology, ecology, chemistry, and medicine. However vital those studies are, they cannot proceed without knowledge of the size and location of the stresses. Since most stresses are intimately bound up with economic activity any assessment of future environmental stresses requires quantitative economic projections. SARUM is a model which provides quantitative projections of many economic variables and so is a suitable tool for providing estimates of future stress levels. It should be emphasized here that long-term economic models cannot provide forecasts; the vagaries of world politics can confound any prediction. Therefore such models can only be used for providing conditional forecasts, answering "What if?" questions. The set of assumptions needed to perform a model simulation is usually termed a scenario. Several scenarios will be discussed in the next section where it will be seen that very different futures can arise from different assumptions. The value of the model exercises lies in the help that they give towards understanding a complex system where many interactions are involved.

Many important stresses are associated with direct release of substances or energy into the environment (e.g. solid wastes from mining and waste heat from power stations). The laws of conservation of matter and energy (ignoring relativistic effects) allow a self-consistent material–energy balance approach to be used (Pearce, 1976; Victor, 1972). Figure 2 shows the flows of material or energy in the environment–economy system. It

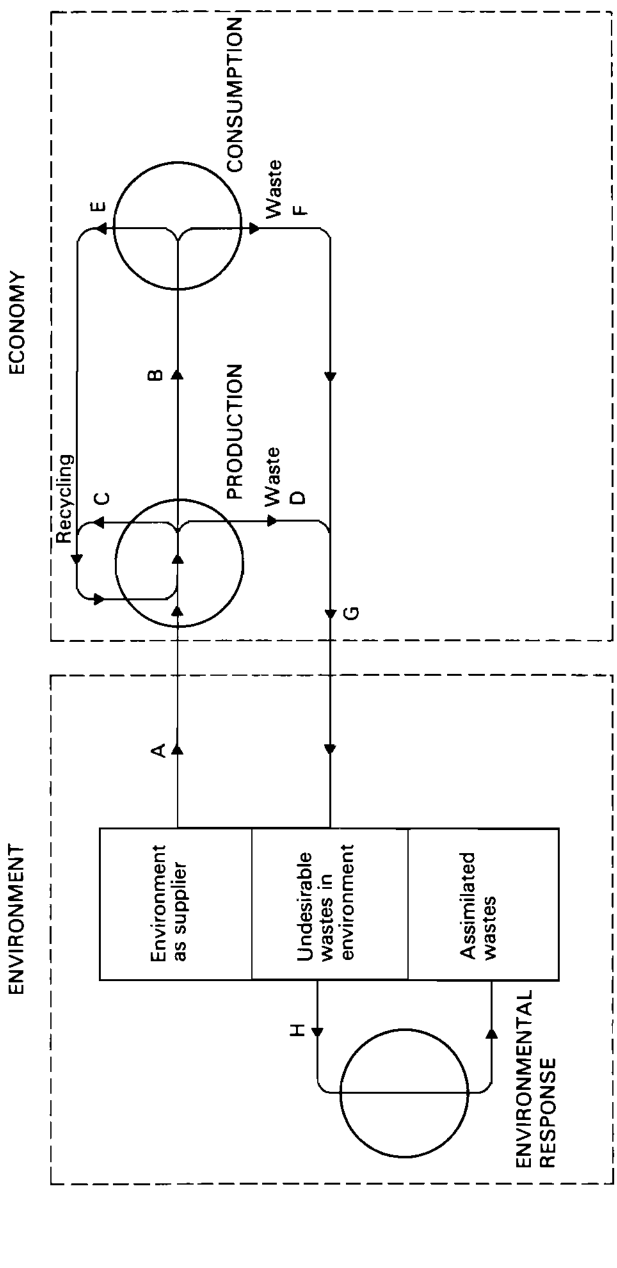


FIGURE 2 Material/energy flow in the environment–economy system.

can be seen that there is a flow of raw materials from the environment (A), acting in the role of supplier (e.g. minerals extraction), which then goes into the production sector where it is transformed into goods for consumption (B) and waste is either recycled (C) or discharged (D). The flow to consumption is eventually either recycled (E) or discarded (F). There is obviously some buildup in these sectors associated with capital equipment in the production process and consumer durables. However, it can reasonably be assumed that all human artifacts have a finite life and are eventually recycled or discarded. The total waste flow (G) returns to the environment. Some of these wastes (H) can be assimilated, at varying speeds, by the environment. As mentioned before, the response of the environment to stresses is a complicated topic requiring specialist knowledge. Therefore the first step in the present study is to restrict our analysis to the workings of the economy and its direct connections with the environment. Using the notation of Figure 2, this implies that assessment of environmental effects will be restricted to flows A and G, i.e. the extraction of material and energy from the environment and their ultimate disposal as waste. However, this does not preclude the study of impacts at some future stage.

The stresses which are to be investigated must depend on economic variables available in the model. In many cases a simple coefficient will suffice, e.g. the number of tonnes of sulfur dioxide released for every tonne of coal burnt. However, more complicated relationships could be used which take into account such things as the increase in mine wastes per tonne of metal content as ore grades decline. Assumptions can also be made about how these coefficients may change over time, perhaps as a result of greater pollution controls or an increase in recycling. Such assumptions will form part of the scenario and are an essential component of any analysis and discussion of the final results. Finally, apart from stresses which are a function of economic variables, some model outputs can be considered as environmental-stress indicators without any further transformation. Obvious examples are connected with agriculture where there is concern about such problems as the acceleration of soil erosion due to more intensive farming, the runoff of fertilizers into water courses, and the increase in salination caused by irrigation. The yield per hectare and the total fertilizer and irrigation water consumed are available directly from the model and would be suitable indicators for the problems just mentioned.

3 RESULTS

A reference simulation was carried out against which several other variant scenarios could be compared, all of them using the regional disaggregation of Figure 1(b). Such an approach is useful for drawing inferences about what are the important factors in the problems under consideration. The reference experiment uses the low growth rates of Interfutures Scenario B2, approximately based on extrapolation of trends in the late 1970s. However, the trade assumptions are different in that the biases (Parker, 1977) are assumed to be constant rather than falling. The biases represent the factor by which any particular trade flow (e.g. food exports from Australia to Western Europe) is less than that which would be expected in a perfect free-trade world, with due allowance having been made for price differences.

The stresses that we shall examine relate to the disposal of solid waste in the environment. These discharges form a self-contained set on which data are readily available. The source that we have used is Beretka (1978). One point which is worth drawing attention to about the disposal of solid wastes in Australia is illustrated in Figure 3. The great majority of the population live near the coast but, as can be seen, many of the stresses associated with mining and industry are also situated in this area. The stresses and the model variables to which they relate are shown in Table 1. All are related by simple coefficients apart from domestic waste which is a linear weighted function of the three components.

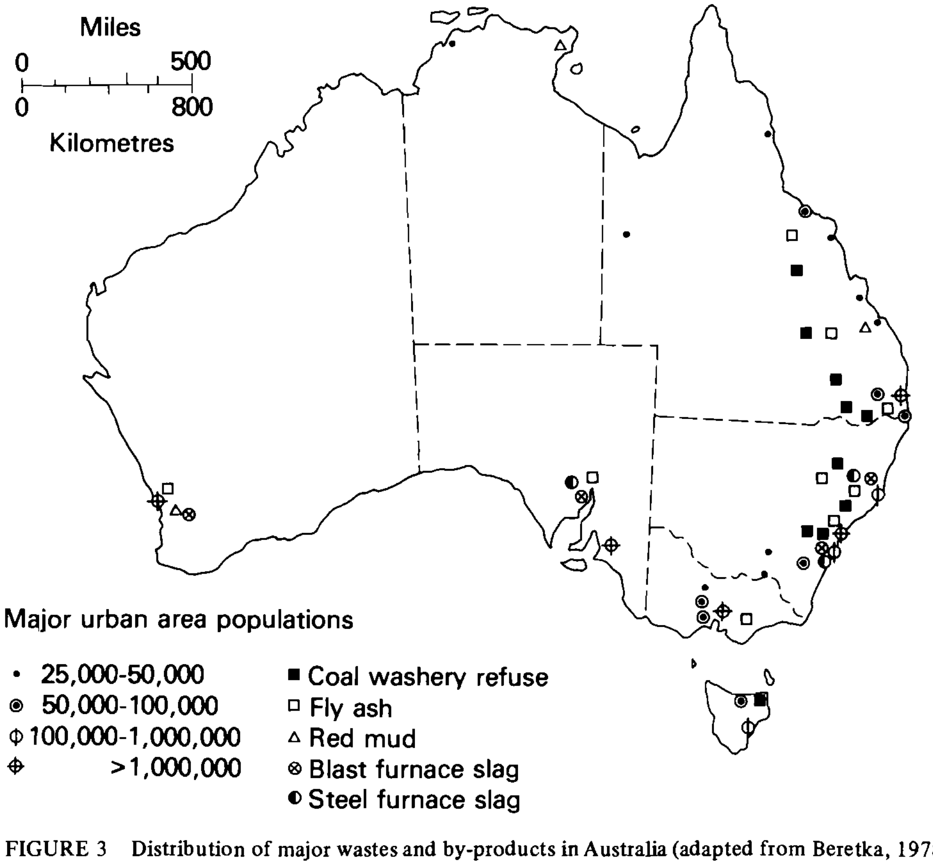


FIGURE 3 Distribution of major wastes and by-products in Australia (adapted from Beretka, 1978). (Map by courtesy of CSIRO Division of Building Research, Australia.)

Figures 4 and 5 show the release of solid wastes into the environment associated with the reference experiment. All coefficients were set so as to give the correct values for waste production in 1975. The coefficients were assumed to be constant, which implies that an unchanging fraction is recycled. The most striking result is the increase in the discharge of coal wastes. This is associated with the growth in Australia's exports of energy,

TABLE 1 Stresses and the activities causing them.

Stress	Activity in economic model
Waste from coal washeries	Production of energy
Fly ash from power stations	Consumption of energy
Mine tailings	Production of minerals
Red mud from bauxite refining	Production of minerals
Slag from ferrous-metal production	Manufacturing production
Slag from nonferrous-metal production	Manufacturing production
Domestic waste	Final consumption of manufactures, natural products, and food

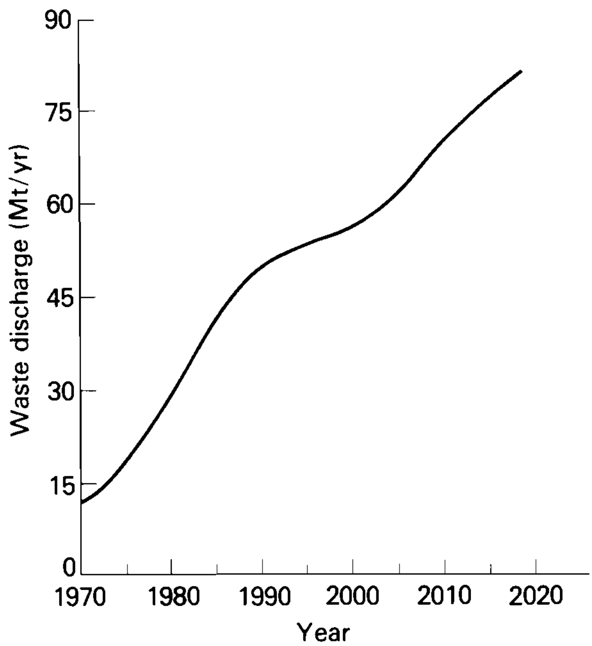


FIGURE 4 Wastes from coal washeries (reference experiment).

mainly to Japan. The growth rate of energy production between 1970 and 2020 is 3.8% year^{-1} compared with an average for the whole economy of 2.5% year^{-1}. The growth rate in minerals production over the same period is 2.8% year^{-1} which, though not so great, still leads to very large amounts of red mud to be disposed of. According to Beretka (1978) there is no economic way of reusing either of these two major waste products. Given the level of energy and minerals production, the figures for wastes are likely to be underestimates because of depletion. As more and more coal is extracted it is likely that thinner seams and lower-quality coal will have to be mined, which will result in more waste per tonne of coal.

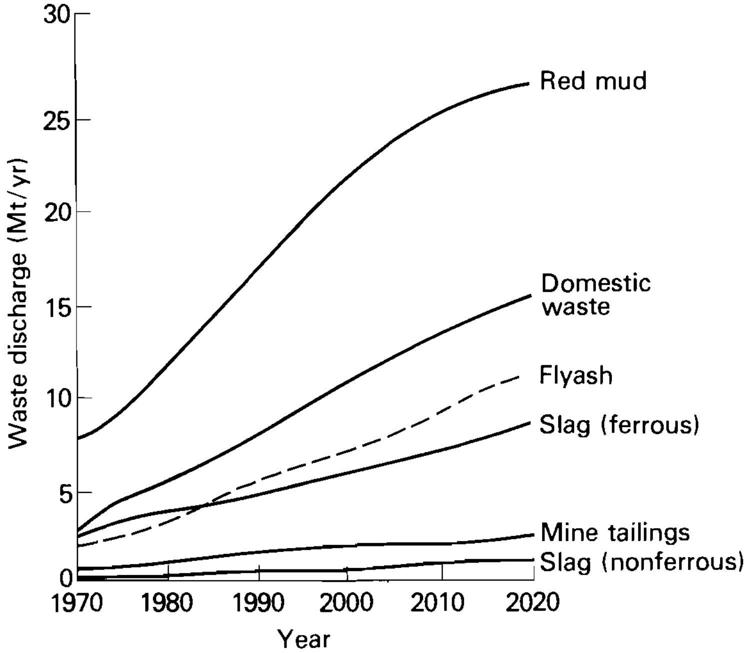


FIGURE 5 Solid wastes from various sources (reference experiment).

One possible economic future for Australia would be to pursue a policy of close economic links with its neighbors in the West Pacific. An experiment was performed in which the trade biases between Australia, New Zealand, Japan, and East and Southeast Asia fell from 1980 onwards towards the lowest values observed in the world at rates commensurate with those observed in the EEC. The general picture that emerges is that Australia moves even more in the direction of being an exporter of primary products and an importer of manufactures. The effects on the discards of coal waste and red mud are shown in Figures 6 and 7. It can be seen that as a consequence of greater exports the trade liberalization leads to an increase in the production of energy and minerals in Australia with a consequent rise in the quantities of coal and mineral wastes. The sudden changes which occur in the coal-waste curve arise from the fact that with freer trade consumers can switch rapidly from one supplier to another as differential depletion affects relative prices.

The liberalized-trade scenario benefits Australia in gross consumption per person (17% higher in 2020 than for the reference experiment) but at the expense of greater environmental degradation associated with mining and minerals extraction. However, because many more manufactures are imported, environmental stresses associated with industrial production are reduced. For example, in 2020 the slag from ferrous metals discarded drops from 8.2 Mt $year^{-1}$ to 4.8 Mt $year^{-1}$.

The idea of Australia becoming a quarry and mine pit for other countries may not be attractive to its citizens. Therefore a scenario was postulated in which both exports

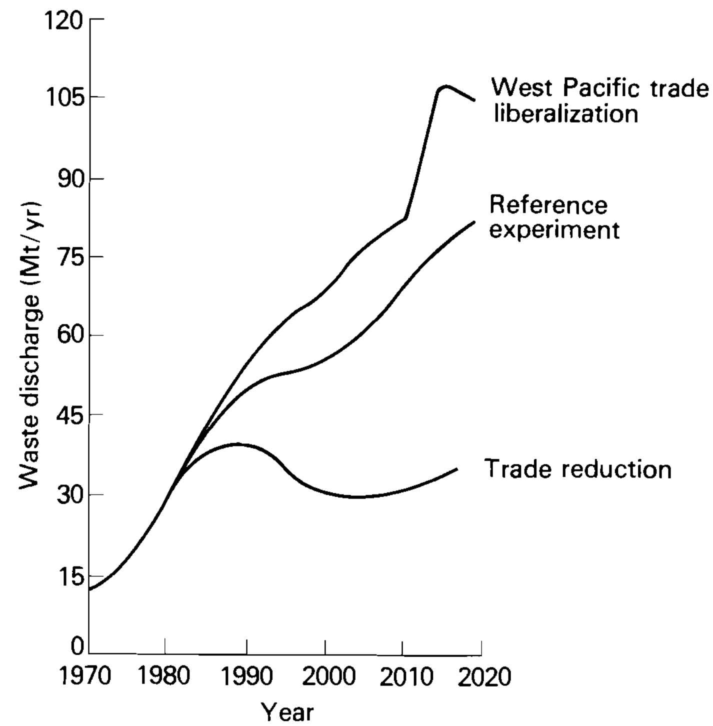


FIGURE 6 Wastes from coal washeries for various scenarios.

of energy and minerals and imports of manufactures were reduced from 1980 onwards. The biases were changed at the same rate as for the liberalization experiment but in the opposite direction. This is feasible because these trade flows, in money terms, approximately cancel each other out. Figures 6 and 7 show the environmental consequences. The reductions in stress are very great indeed as exports are restricted. However, from 2005 onwards, once exports are very small, Australia's own rising requirements lead to an upward turn in the stress levels. Also a price has to be paid for this environmental improvement. Because there is import substitution of manufactures, stresses associated with industry increase. Compared with the reference case, the discards of slag from ferrous metals are 18% higher by the end of the experiment. The most important adverse effect is a fall in the standard of living of almost 10%. The tradeoff curve is shown in Figure 8. This shows the fall in consumption per person against the fall per person in discards of coal waste. It is interesting to note the increasing marginal cost; as time goes by a given reduction in stress implies a greater and greater reduction in consumption.

As mentioned earlier, the model outputs can be used directly as environmental indicators. Some results from the three scenarios discussed are shown in Figures 9–11. The rise seen in each indicator towards the end of the simulations is due to increased exports of food to East and Southeast Asia. This region's increased imports are caused by its rising standard of living and growing population which increase the demand for food, but

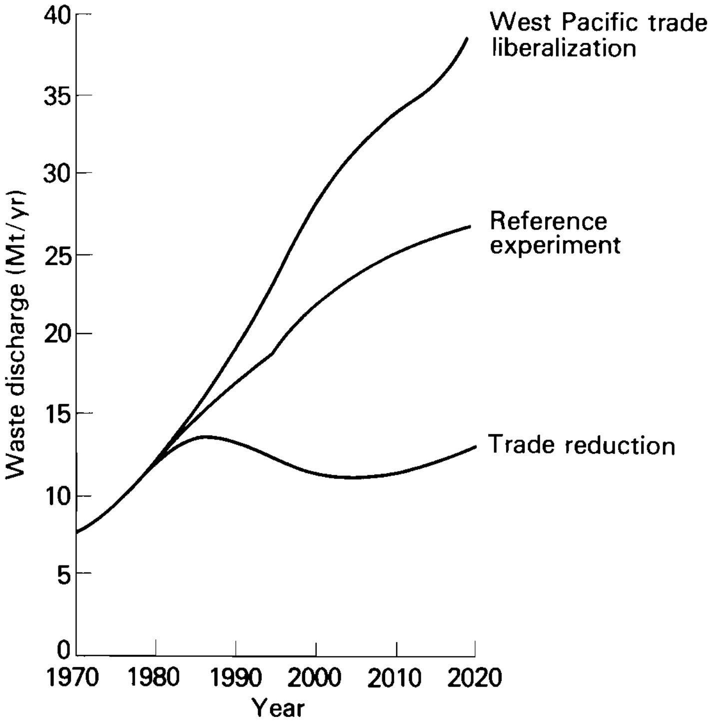


FIGURE 7 Red-mud wastes for various scenarios.

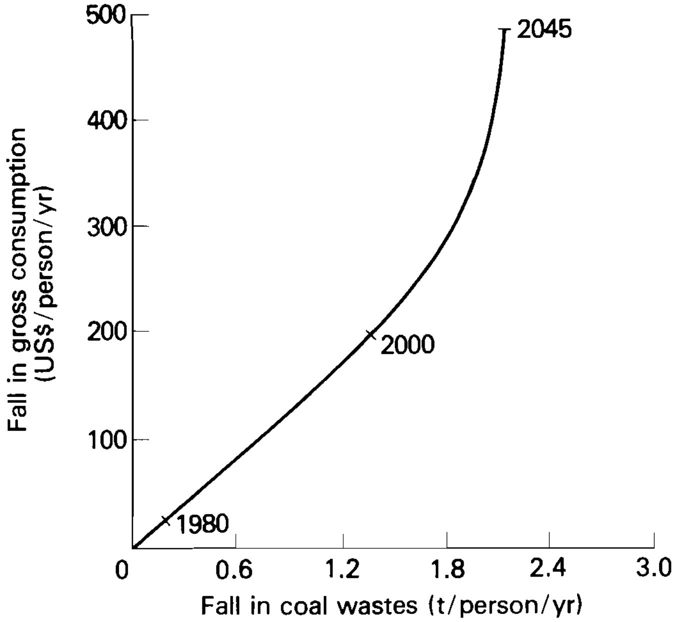


FIGURE 8 The tradeoff between coal waste and consumption.

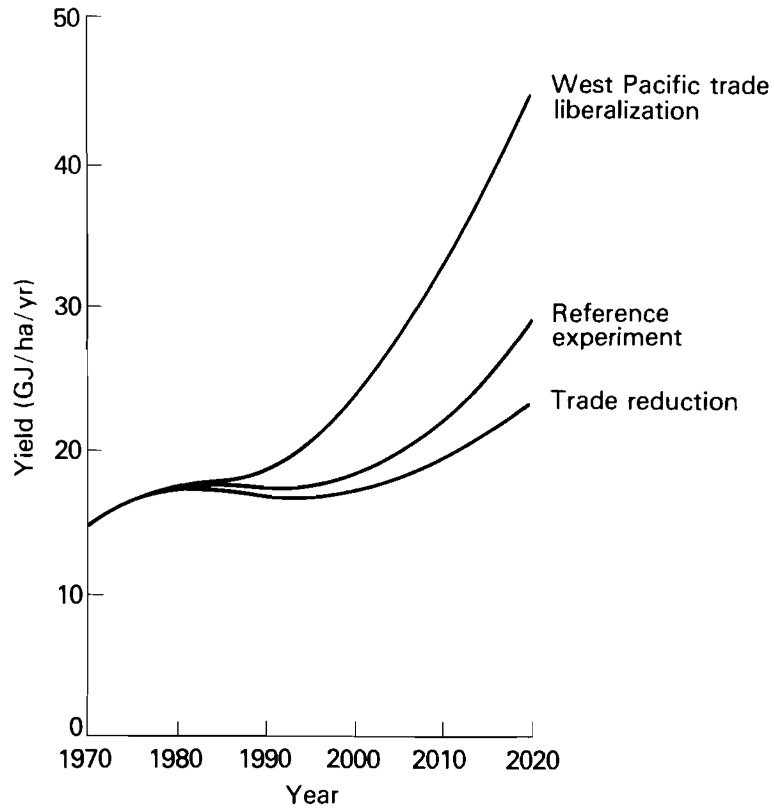


FIGURE 9 Yield per hectare (in gigajoules of cereal equivalent) for various scenarios.

since the potential of the countries in the region for increasing production is severely limited they must import. The liberalization of trade in the Western Pacific greatly enhances this trend and the environmental impacts on the Australian countryside could be very considerable; the total fertilizer consumption in 2020 is triple what it is in the reference experiment.

Only a limited number of results have been presented here but they indicate the scope of possible studies of the environmental consequences of economic actions which can be carried out using a model such as SARUM. The results should only be taken as broad indicators of what might happen to the environment. The disaggregation of the Australian economy into only 11 sectors is too coarse to capture many affects precisely. Also the assumption that the coefficients are constant is obviously open to doubt; new techniques and recycling could reduce them. However, waste is inextricably associated with mining and quarrying and has little potential for recycling as, say, building materials (Beretka, 1978). Therefore is seems inevitable that if Australia continues on the path of being a large exporter of coal and minerals very large quantities of solid waste will have to be disposed of in the environment.

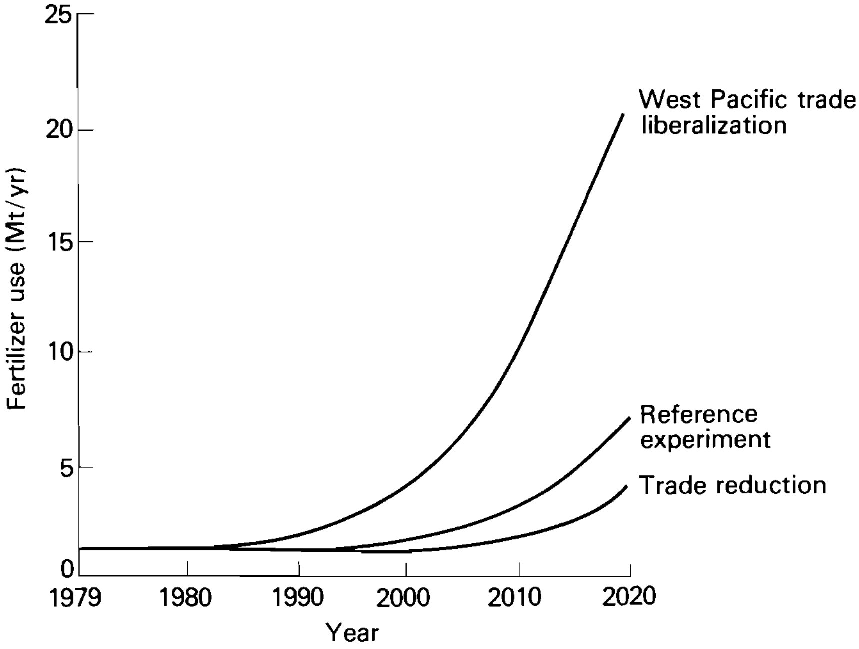


FIGURE 10 Total fertilizer use for various scenarios.

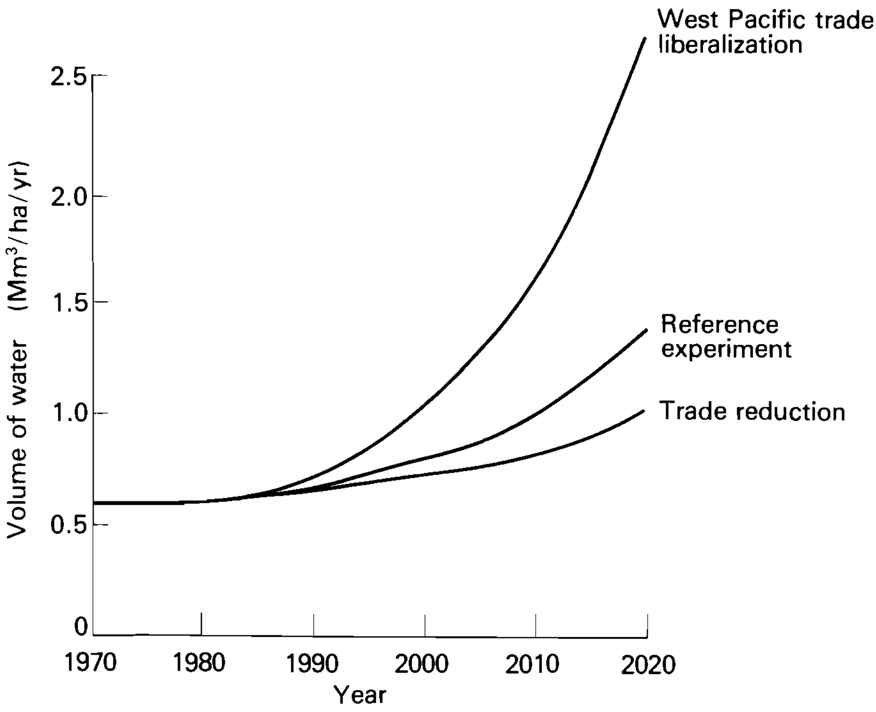


FIGURE 11 Total use of irrigation water for various scenarios.

4 FURTHER DEVELOPMENTS OF THE ENVIRONMENTAL SUBMODEL

The preliminary stage of the SARUM–AREAM study has been described; there are several extensions which are actively being considered. One direction for further work has already been described, i.e. the analysis of environmental impact. The way in which the assimilative capacity of the environment is reduced by further environmental stresses can be very important, and the work of Torres and Pearce (1979) in this field could be very useful.

Many other important improvements involve facing the problems of evaluating environmental damage in monetary terms. Many approaches have been made based on cost–benefit methods in which direct attempts are made to evaluate environmental damage (Kolm, 1974; Coomber and Biswas, 1973). However, such methods do not adequately take into account political effects or influences that might be thought of as ethical or psychological. A very well-known example of how cost–benefit analysis in the environmental–economics field can fail is the Report of the Commission on the Third London Airport (HMSO, 1971). This was one of the most comprehensive cost–benefit studies ever carried out in the UK, yet the Government rejected its recommendations within one month of receiving the submission, largely in response to political pressures from residents near the proposed site. Another example of the pure market-economy approach is found in Hore-Lacy (1976), where the value of timber production in the Jarrah forests of Western Australia, $20 per hectare per year, is weighed against the value of the bauxite under the forest, $1,000,000 per hectare.

Approaches which leave out people's nonmarket attitudes towards the environment are open to criticism and it would seem appropriate for this project to take a scientific approach steering clear of value judgements. What a model such as SARUM can do is produce tradeoff curves of the type shown in Figure 8. These show what other benefits have to be foregone in order to achieve a certain amount of stress reduction. The position on the curve at which society chooses to operate results from social and political actions. Some further insight can be gained by analyzing revealed tradeoffs inherent in past decisions. For example, in the case of the Third London Airport it would be possible to deduce a lower bound on the revealed cost of disturbance to residents. Such figures could be one input to similar decision-making processes in the future. For example, one could say that if some airport is to be built then that decision might imply a valuation of disturbance to residents of, say, less than half that revealed by the residents near the 1971 proposed site. Although such results are deducible from observations of the real world and can thus be classed as scientific it is not valid for them to preempt future decisions as people's attitudes to the environment can change greatly.

Another way of obtaining these curves is to close the feedback loops between the environment and the economy. This will probably be the main area of further development in the project. One way of doing this is to invoke the "polluter pays" principle in which certain pollution-abatement measures are required of stress-producing activities. These measures have to be paid for, with a resulting increase in the costs of production. Eventually the final consumer will have to pay higher prices which will result in a lower standard of living. It will be very straightforward to introduce such requirements into the model, and again a tradeoff curve relating stress reduction to the costs of control will be produced. It will be possible to apply the control costs to different parts of the economy (e.g. the primary producers, the intermediate manufacturing industries, or the final consumers). The effects on the structure of the economy can then be investigated. It is a moot point whether the increase in the production of pollution-control equipment balances the loss of production in the industries responsible for the stress. An economic model will be able to throw light on this question. Such changes in the cost structure of the economy could well affect trade, with Australia losing markets to countries which can produce goods more cheaply as a result of having more lax pollution standards. A model which deals comprehensively with trade, such as SARUM, is well suited for investigating problems of this type.

5 CONCLUSIONS

The way that an environmental capability can be incorporated in a global model has been described and some preliminary results have been presented. It has also been shown how a global model can be used to investigate the problems of one particular country by setting its economy in a world context. As has been seen, environmental stresses in Australia are very dependent on trade policy and the use of a global model has proved very valuable. For example, one can see that the large rise in fertilizer use in Australia is closely connected with rising food consumption in East and Southeast Asia. Global models are not a substitute for more specialized national models; they are complementary, dealing in more detail with the world context at the expense of detail in the home economy. It may indeed prove useful to take the trade flows from a global model and impose them exogenously on a national model. Without doubt, however, it will be advantageous for modelers to get together and discuss their different approaches. This will widen their horizons and help in their understanding of the world, which ultimately must be the aim of economic modeling.

REFERENCES

Beretka, J. (1978). Survey of Industrial Wastes and By-products in Australia. Division of Building Research, CSIRO, Melbourne.

Bruckmann, G. (Editor) (1978). SARUM and MRI, Description and comparison of a World Model and a National Model. IIASA Proceedings Series, Vol. 2. Pergamon, Oxford.

Coomber, N.H. and Biswas, A.K. (1973). Evaluation of Environmental Intangibles: Review of Techniques. Genera Press, New York. (Also published in 1972 by Environment Canada.)

Department of the Environment, Department of Transport, UK (1977). SARUM-76 Global Modelling Project. Department of the Environment, Department of Transport, London.

Friend, T. (1978). Preliminary proposals for a stress–response approach for the organization of a system of environmental statistics for Australia. AESOP Background Paper No. 2. Department of Science and the Environment, Canberra, Australia.

Hore-Lacy, I. (1976). Mining and the Environment. Australian Mining Industry Council, Dickson, A.C.T., Australia.

HMSO (1971). Report of the Commission on the Third London Airport. Her Majesty's Stationery Office, London.

Kolm, S.C. (1974). Environmental damage costs. In, Ascertaining Environmental Costs and Benefits. Organization for Economic Cooperation and Development, Paris, pp. 9–50.

OECD (1979). Facing the future: mastering the probable and managing the unpredictable. Interfutures Final Report. Organization for Economic Cooperation and Development, Paris.
Parker, K.T. (1977). Modeling interregional activity by means of trade biases. In, Proceedings of the IFAC–IFORS–IIASA International Conference on the Modeling and Control of National Economies, 2nd, Vienna, 1977. North-Holland, Amsterdam.
Parker, K.T. and Raftery, J. (1978). The SARUM global model and its application to problems of interest to developing countries. In, Proceedings of the Conference on System Dynamics for Developing Countries. Asian Institute of Technology, Bangkok, Thailand.
Pearce, D.W. (1976). Environmental Economics. Longman, London.
Torres, S.A. and Pearce, D.W. (1979). Welfare economics and environmental problems. International Journal of Environmental Studies, 13(3): 191–200.
Victor, P. (1972). Pollution: Economy and Environment. Allen and Unwin, London.
Wagstaff, H. (1979). Food policies and prospects, insights from global modeling. Food Policy, August: 155–168.

DISCUSSION

Asked by several participants, Parker *explained that his model displays both physical relationships describing agricultural production and reactions to market forces. As to energy, the model contains depletion functions which relate the cost of producing fossil fuel to the cumulative amount produced; trade depends on prices, prices depend on cost of production but also on assumptions about the future behavior of producers (the Organization of Petroleum Exporting Countries). In food production a similar procedure is applied.*

Mesarovic *stressed the problématique of forecasting properly the nonlinearities of the physical relationships in agricultural production which are different from monetary relationships.*

Parker *replied that, in his model, cost includes profits, i.e. a reasonable return on investment. Cost considerations are then modified for imbalances between supply and demand as part of the equilibrating scheme which balances supply and demand over time. The model is not primarily designed to deal with arbitrary price changes based on political or monopolistic power.*

ASSESSING THE IMPACT OF PACIFIC ECONOMIC COMMUNITIES ON AUSTRALIA AND NEW ZEALAND USING AREAM*

J.M. Mula, D. MacRae, and K.T. Parker**
Department of Science and the Environment, Lombard House, Canberra, A.C.T. (Australia)

1 INTRODUCTION

The Australia Resources and Environmental Assessment Model (AREAM) has used the Systems Analysis Research Unit Model (SARUM) as a basis for quantifying stress on the environment at the national level resulting from the impact of trade and demographic change throughout the world. In this paper we consider some of the trade scenarios underlying the case studies that dealt with the types of stresses on the Australian environment considered in the foregoing paper (this volume, pp. 33–47). These scenarios deal with various types of economic communities around the Pacific, each containing Australia and New Zealand as separate countries.

2 A REFERENCE SCENARIO

A reference scenario is required to assess the effects of policy changes as evaluated by a model such as AREAM. It suits our present purposes to use as a reference the scenario of low economic growth worldwide proposed by the Interfutures Project (OECD, 1979), which was a large-scale global research study that was recently completed. Evaluation of this scenario was effected by the Interfutures Project using SARUM. This evaluation provides the context for the following analysis of the development of Australia and New Zealand relative to alternative economic communities within the Pacific Basin.

---

* The views expressed in this paper do not necessarily reflect the opinions of the Department of Science and the Environment, nor of the Australian Government.
** On secondment from the Department of the Environment, London, UK.

Major assumptions underlying this scenario of low economic growth include (1) zero recovery with respect to the productivity losses incurred during the years of this decade, (2) an annual growth rate of 1.5% in long-term productivity in the United States, (3) a gradual convergence in the long-term productivity of the other countries of the Organization for Economic Cooperation and Development (OECD) to US levels, and (4) a rate of population growth equivalent to the UN medium-level projections and, relative to these projections, a constant rate of labor-force participation. Over the 25 years to the year 2000 this yields an average rate of growth in GDP of 3.4% for all OECD countries, with Australia and New Zealand registering 3.3% and 2.7%, respectively. Under the same conditions the model indicates that Japan and East and Southeast Asia will register the higher rates of growth of 6.6% and 6.4%, respectively.

The reference scenario used here resembles the Interfutures scenario for low economic growth in all aspects except the following: (1) trading patterns are set, using a mechanism to reflect the extent of bias in trade between countries, according to the historical experiences of the early 1970s such as the action of the Organization of Petroleum Exporting Countries (OPEC) cartel in 1973; (2) conditions set to liberalize trade between North and South are removed; (3) conditions set to create a flow of official aid from developed to developing countries are removed.

3 A MECHANISM FOR EFFECTING TRADE LIBERALIZATION

The methodology used for modeling trade between various sectors of the world regions is described elsewhere (Parker, 1977). The mechanism which describes how free-market conditions or trade liberalization are induced is based on the use of trade biases. A matrix of trade biases is applied to each commodity traded in order to modify the prices perceived by the importer depending on the source of the commodity. This bias explicitly accounts for factors such as distance and politics, which inhibit the functioning of a free-trade market. By adjusting the elements of the trade-bias matrix of each of the commodities considered here we are able to use the model to evaluate trade policies relating to the levels of liberalization and protectionism over time which a region might wish to pursue in the context of a specific economic scenario.

The trade policies considered in this paper relate to reduction in the tariff barriers between various regions and/or countries in the Pacific Basin. The word liberalization is used because a perfect free-trade agreement would mean that trade biases would be eliminated. This would imply that imported commodities could compete perfectly with home-produced goods. Since the biases subsume the barrier of distance this would mean that transportation costs were nonexistent or negligible, which is not the real-world situation. For this reason alone the biases only fall to the lowest values observed in Australia and New Zealand in 1970. These ranged from 2 to 4 depending on the particular commodity, where a value of unity represents perfect free-trading conditions.

In keeping with past change, this liberalization of trade was introduced gradually. From 1980 trade biases were reduced at the rate of 10% per annum to approach the lowest value of the particular commodity observed in practice. This reflects the rate of change in tariff barriers throughout the European Economic Community. Thus trade biases would have dropped to about 11% of their original value by the year 2000.

To gain insight into how different regions would react to liberalization of trade, various simulations introducing each region or country separately into a trading union were completed. This allowed measurement of the differences in a region's or country's economic performance in the comparison between when the region or country is included and when it is excluded from a particular trading union.

4 PACIFIC ECONOMIC COMMUNITIES

To date experiments have been conducted which have evaluated the reference scenario (and other Interfutures scenarios) in relation to a series of economic communities in the Pacific Economic Communities (PECs) as follows:

PEC-0	Australia and New Zealand (ANZ)
PEC-1A	ANZ + Japan
PEC-1B	ANZ + East and Southeast Asia (ESEA)
PEC-1C	ANZ + Japan + ESEA
PEC-2	ANZ + Japan + ESEA + China
PEC-3	ANZ + Japan + ESEA + China + North America (NORAM)
PEC-4	ANZ + NORAM

The question of whether the economic potential of an overall group of countries or regions and each region in isolation would increase through the development of the economic communities PEC-0 to PEC-4 is considered in this paper. Briefly, from among these seven configurations, the grouping of regions which maximized the lot of Australia and New Zealand by the end of the simulation period occurred for PEC-1C (ANZ + Japan + ESEA). Of the six configurations PEC-1 to PEC-4 the same grouping (PEC-1C) also maximizes the GDP per capita of ESEA. A detailed account of PEC-0 is provided elsewhere (Mula and MacRae, 1979). In this paper the reference scenario is evaluated subject to regional economic communities PEC-1C, PEC-2, PEC-3, and PEC-4.

As a word of caution, the authors view the results presented here and in earlier papers as purely illustrative. Before explicit implications could be drawn from work of this nature more detailed refinement of the structure and assumptions underlying the model would be necessary, particularly in relation to the regional economic subsystems.

5 BROAD COMPARISONS OF PECs

The key finding that emerges from any of the PECs is that any union between developed and developing regions benefits both. However, if there are closer unions between developed regions, particularly in a developed–developing grouping, the larger developed economies tend to take some of the cream from the top of the smaller economies' cake. Still, in such a case all the developed regions attain higher standards of living than if they had stayed out of a union with developing regions.

Using the measure of GDP per capita (expressed in standard 1970 US dollars) as a surrogate for standard of living we see from Figure 1 that in the 50-year period to 2020

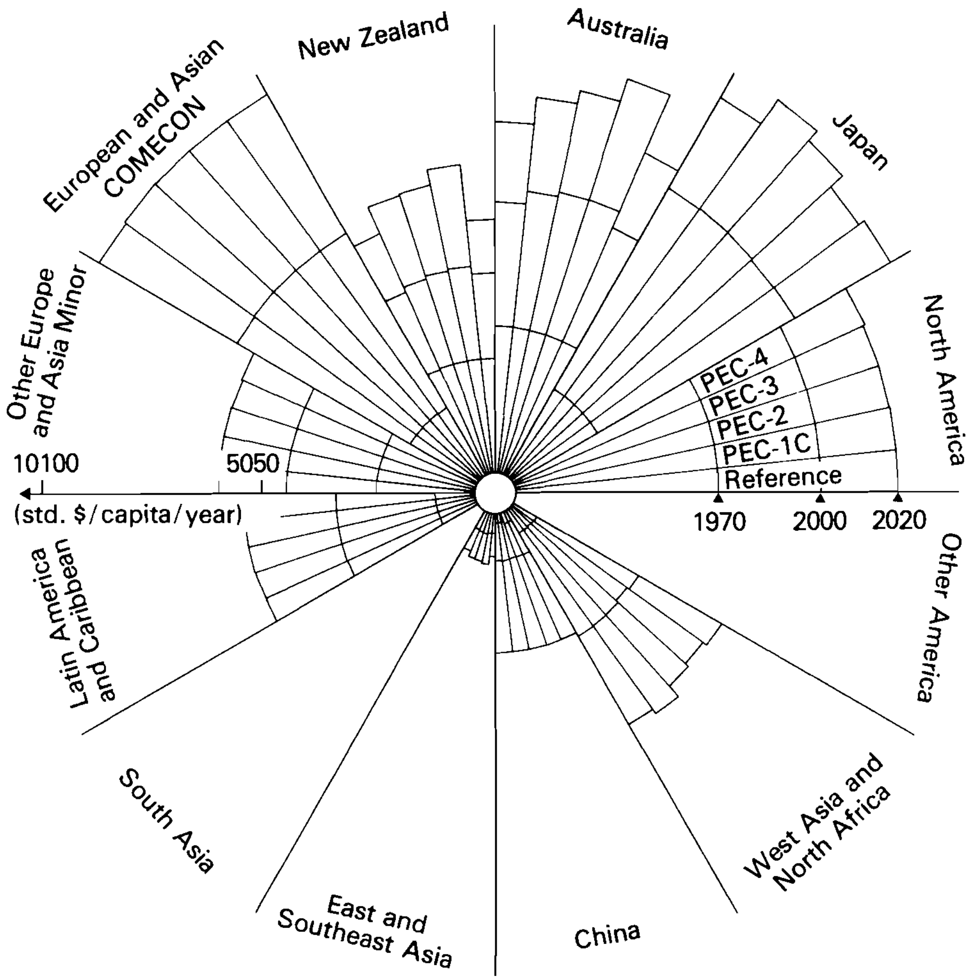


FIGURE 1 Gross consumption per capita per year, by region (in standard 1970 dollars).
Note. For all regions, the innermost arcs refer to the year 1970, the next to 2000, and the outermost to 2020. Within each region, the five sectors (moving counterclockwise) refer to the following scenarios: Reference, PEC-1C, PEC-2, PEC-3, and PEC-4.

model evaluation of the reference scenario generates changes with respect to the ranking of the 12 world regions considered here. Each region reaches its highest and lowest GDP per capita by 2020 with respect to different community formations. North America fares best in PEC-4 and worst in PEC-3. Japan attains the highest GDP per capita with a figure of about $10,000 for PEC-3; PEC-1C yields the lowest level that Japan achieves. Australia peaks at $9020 for PEC-1C and troughs at $7680 for PEC-4 which is the same level as the reference scenario. New Zealand, in contrast, would increase its GDP per head in all community combinations, faring best in PEC-1C with a figure of $6850. ESEA improves every time a region is added to the community, and reaches its highest level of $1500 in PEC-3. These results lead us to anticipate the result that its lowest figure occurs in relation to the case when it is omitted from the community. China exhibits little variation in its GDP per capita; the values for the reference scenario and the four communities range from \$3342 to \$3364. The lowest value occurs when all regions are grouped (PEC-3) and the highest value results for the case in which there is no formal grouping with other Asian countries (PEC-4). Other regions not in one of these communities stay relatively stable except for West Asia and North Africa (WANA) which suffers a drop in the case of PEC-3 when North America is able to obtain energy supplies from China, ESEA, and Australia at increasingly attractive rates. Any community formation between developed countries and developing countries of Asia produces a deterioration in the standard of living of the poorest countries of the noncommunity regions of South Asia and Africa other than WANA.

In terms of gross production as shown in Figure 2, GNP per capita for Australia and New Zealand is dwarfed by that of the larger population regions of China, Latin America,

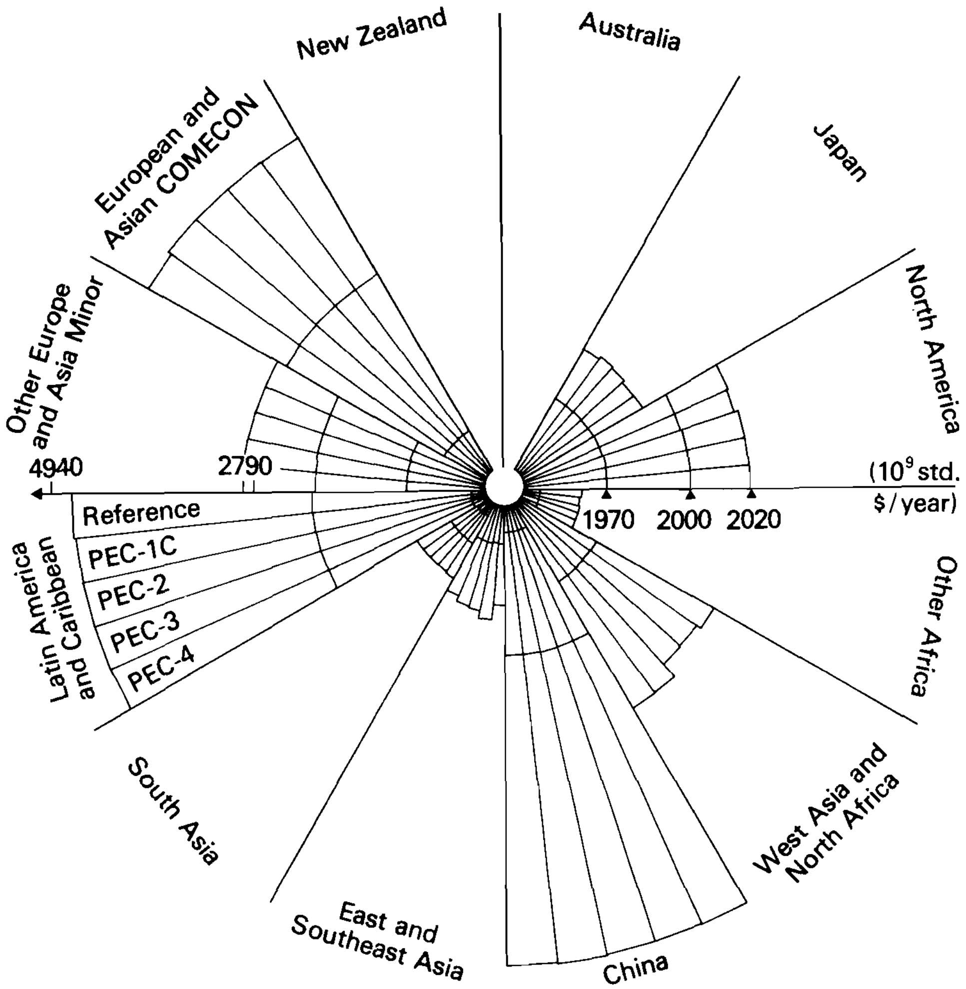


FIGURE 2 Gross production per year, by region (in 10^9 standard 1970 dollars). See also the Note under Figure 1.

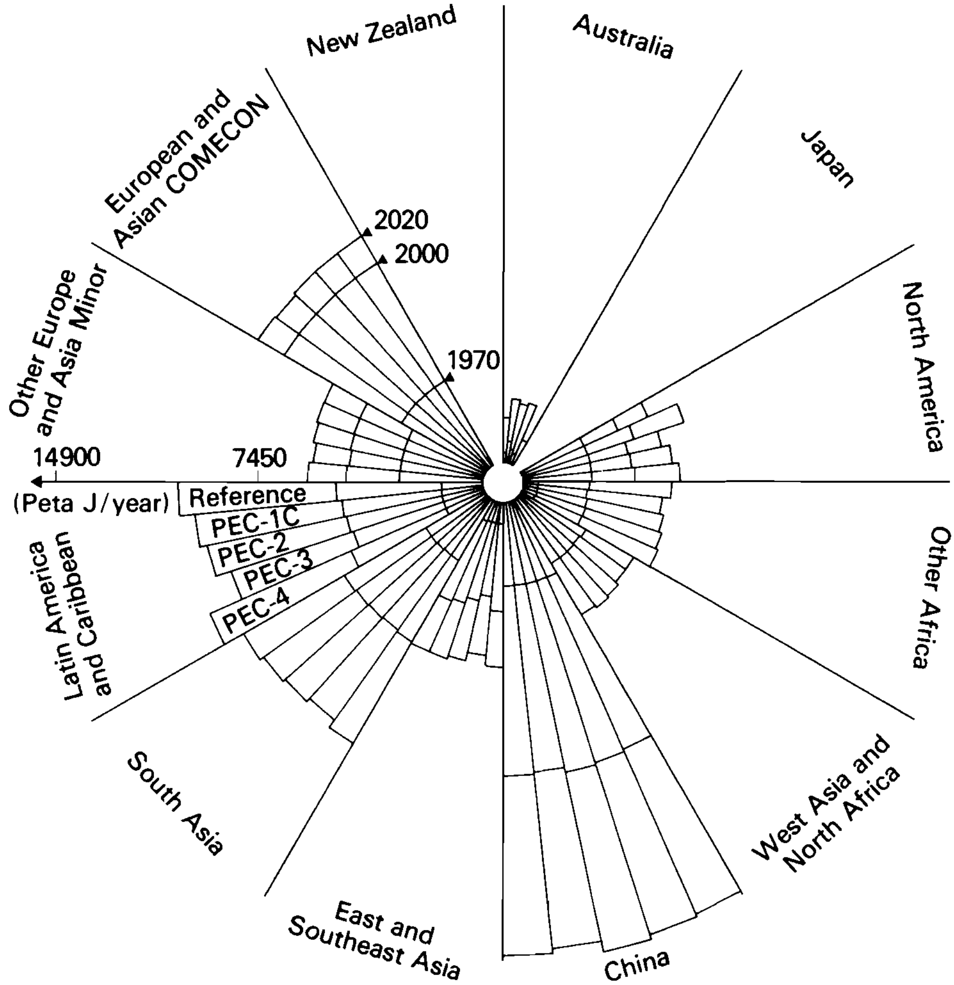


FIGURE 3 Sales of food per year, by region (in petajoules of cereal equivalent). See also the Note under Figure 1.

and the European and Asian COMECON countries. The production of each of North America and West Europe takes until 2020 to reach the COMECON level for the year 2000 (given the somewhat high growth rate for COMECON set in the so-called low-growth reference scenario). Some appreciable positive variations can be seen in the production of ESEA, particularly as a result of PEC-3. The WANA level for the reference scenario is higher than for any of PEC-2, PEC-3, and PEC-4.

Turning now to food production, Figure 3 shows the sales of food per year by region measured in petajoules* of cereal equivalent. Although this measure equates both

* 1 petajoule = 10^{15} joules.

cereal and animals as being interchangeable it gives a good macromeasure of the food-producing capabilities of a region, given the physical constraints of that region. As can be seen from the polar graph, North America's access to the Asian market, particularly ESEA, has a dramatic effect on its production. This effect is shown in Figures 4(a) and 4(b) when the ESEA share of NORAM's exports jumps 17 percentage points (from 15% to 32%) by the year 2020 in the case of PEC-3 with respect to the reference scenario. Appreciable increases are also realized by China. In both these cases these increases are gained at the expense of reductions occurring mainly in Western Europe and WANA. Apart from Australia (to be discussed later), the other region that is appreciably affected is Latin America and the Caribbean (LACARB). This region experiences reductions in food production in relation to each of the PECs, particularly when North America participates.

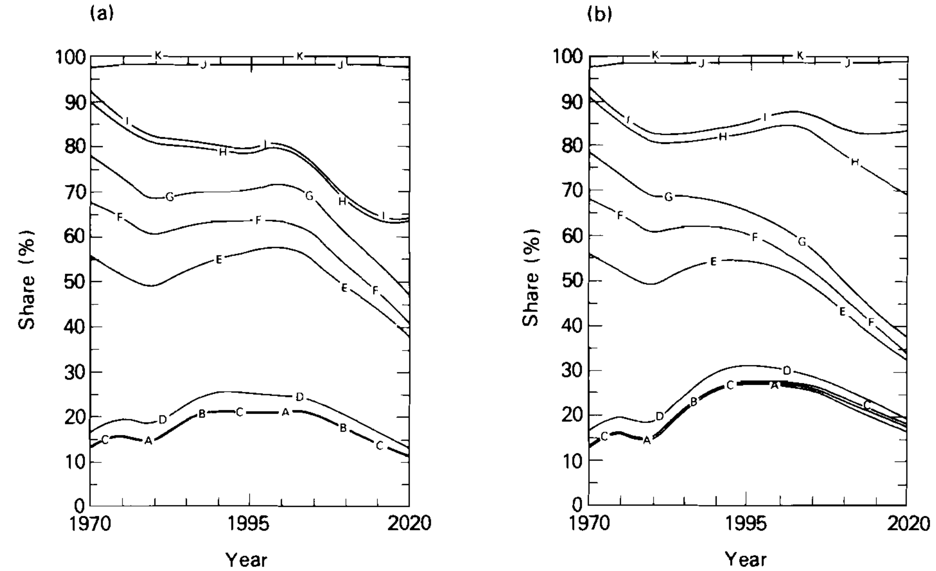


FIGURE 4 Shares of exports of food by NORAM: (a) standard run; (b) PEC-3. The areas under the curves are the shares of NORAM total food exports going to the following regions: A, Japan; B, Australia; C, New Zealand; D, European and Asian COMECON countries; E, Other Europe and Asia Minor; F, LACARB; G, South Asia; H, ESEA; I, China; J, WANA; K, Other Africa.

Disparities in food consumption per capita are shown in Figure 5. Australia and New Zealand reach the glut limit early in the simulation period. This limit is an expression of the amount a person can physically consume. Although the expenditure on food continues to increase for the rich countries we assume that they are buying more expensive food and also are paying more for services such as retailing, preparation, and catering. The glut limit is set to 20 gigajoules per person per year and is the cereal equivalent of Australian food consumption in the early 1970s. Although increasing wealth in ESEA leads to more than a doubling of its food intake in PEC-1C by 2020 this is only a third of the consumption per capita in Australia, while Japan's consumption more than doubles

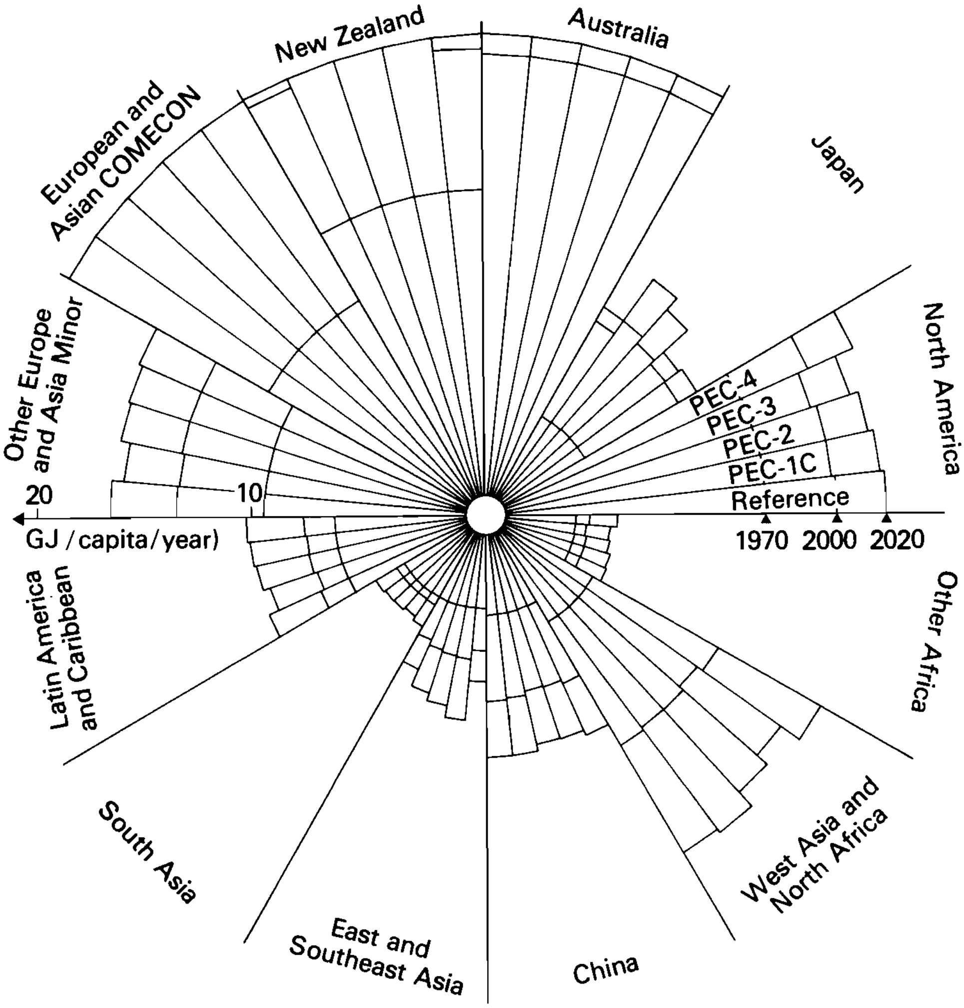


FIGURE 5 Food consumption per capita per year, by region (in gigajoules of cereal equivalent). See also the Note under Figure 1.

to reach 11.5 gigajoules per person by the same year. Although the largest food producer, China, achieves a consumption level similar to that of Japan and LACARB, the size of the population to be fed is much greater.

6 EFFECT OF THE PECs ON DOMESTIC MARKETS IN AUSTRALIA AND NEW ZEALAND

An assessment of how the various PECs considered here affect Australia and New Zealand is shown in Figure 6 in terms of GDP per capita for the following cases: A, the

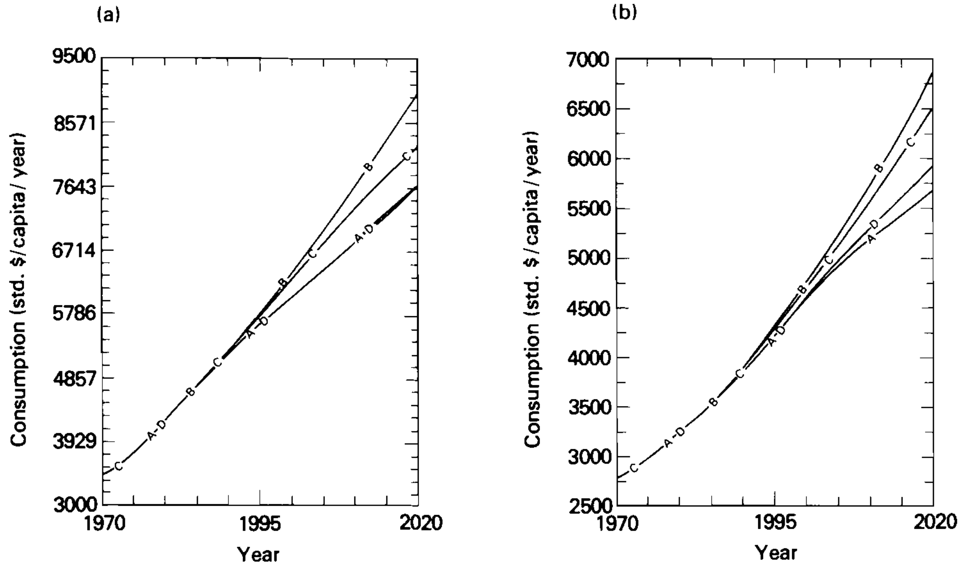


FIGURE 6 Gross consumption per capita; (a) Australia; (b) New Zealand. The curves refer to the following scenarios: A, reference scenario; B, PEC-1C; C, PEC-3; D, PEC-4.

reference scenario; B, PEC-1C (ANZ + Japan + ESEA); C, PEC-3 (PEC-1C + China + NORAM); D, PEC-4 (ANZ + NORAM). The outputs from these cases are labeled as just indicated throughout the rest of the paper unless otherwise stated. For both Australia and New Zealand the PEC-1C community produces the highest standard of living expressed in terms of GDP per capita. All these groupings produce levels of GDP per capita exceeding those of the reference scenario.

In an attempt to determine which areas of both economies produce this increased standard of living we shall examine the productive output of individual sectors. The manufacturing sector in both Australia and New Zealand shows a downturn in sales (Figure 7). The major effect on Australian manufacturing industry is brought about by the PEC-1C run where the cheaper labor of ESEA makes this area of the economy much less competitive. Even in the PEC-4 case, where Australian goods at home and abroad only have competition from the manufactured goods of New Zealand and North America, there is a lower rate of production of manufactured goods in Australia relative to the reference scenario. This same pattern of development occurs in New Zealand but to a lesser extent than in Australia for the PEC-1C community. The labor-force requirement (measured in man-years per year) of the manufacturing sector in Australia falls to half the number of the reference run by 2020 as a result of the PEC-1C grouping but the total labor force for all sections shows a marginal increase for the same comparison.

Some of the additional labor force is taken up by the energy and minerals sectors in Australia but most jobs are created in the service sector. With the increase in energy production in the PEC-1C run (Figure 8), jobs are created as a result of the greater exports, particularly to Japan. However, as can be seen from the PEC-3 run this market is not

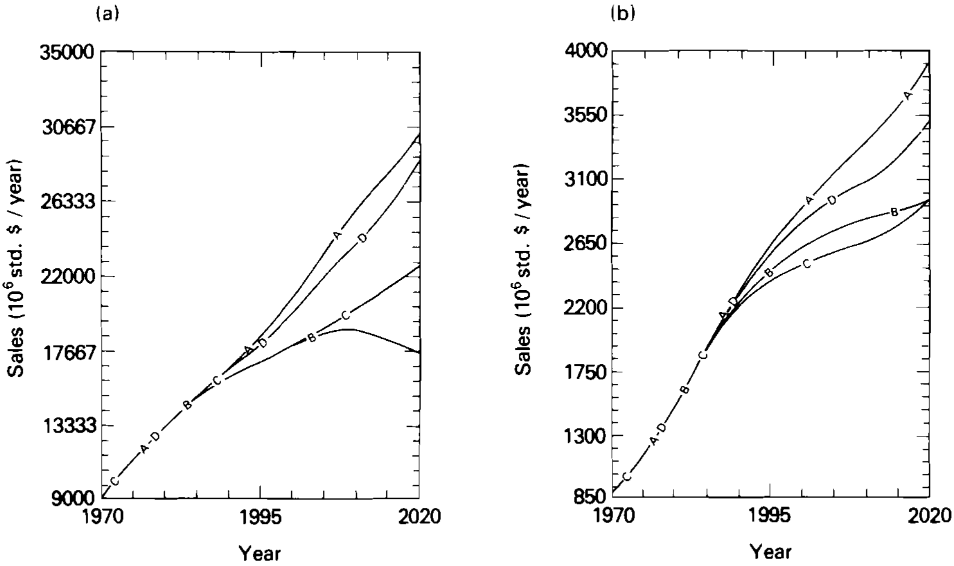


FIGURE 7 Sales of manufactures per year: (a) Australia; (b) New Zealand. The curves refer to the following scenarios: A, reference scenario; B, PEC-1C; C, PEC-3; D, PEC-4.

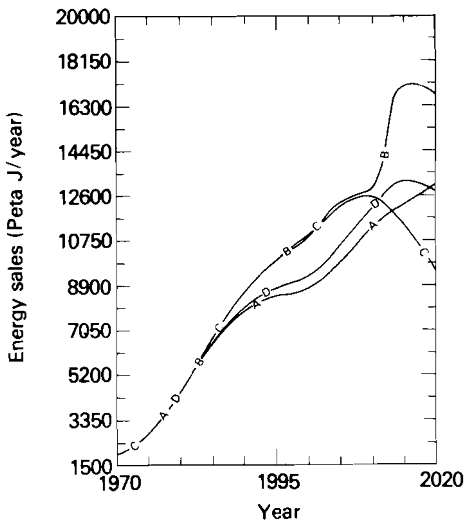


FIGURE 8 Sales of energy per year by Australia. The curves refer to the following scenarios: A, reference scenario; B, PEC-1C; C, PEC-3; D, PEC-4.

reliable. This arises because the Japanese show a preference for the NORAM market as North America enters the community. A clearer picture of this shift can be seen from a comparison of Figures 9(a) and 9(b). The North American share of the Japanese energy market by 2020 moves from 20% for PEC-1C to nearly 60% for PEC-3 whereas the

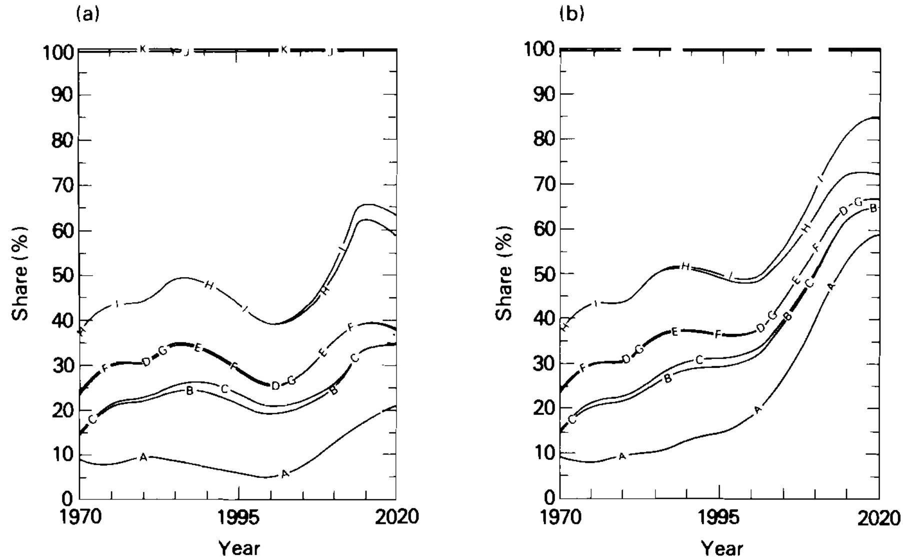


FIGURE 9 Shares of imports of energy by Japan: (a) scenario PEC-1C; (b) scenario PEC-3. The curves refer to the following regions: A, NORAM; B, Australia; C, New Zealand; D, European and Asian COMECON countries; E, Other Europe and Asia Minor; F, LACARB; G, South Asia; H, ESEA; I, China; J, WANA; K, Other Africa.

Australian share falls from 19% (PEC-1C) to 6% (PEC-3) over the same period. In the reference case the share by Australia and North America of the Japanese market by the end of the simulation period (2020) is 18% and 25%, respectively. At the beginning of the 21st century the Australian energy price per unit begins to increase as a result of higher costs of extraction after the easily won coal begins to run out. This produces a situation in the PEC-1C run where the Australian price starts to exceed that prevailing in North America. Thus although North America is not in the PEC-1C community the price difference is enough to cause a downturn in Australian energy production. Mineral production in Australia shows gains for all community arrangements when compared with the reference scenario (Figure 10). The largest gain arises from the PEC-3 grouping. The grouping of Japan and North America generates larger export markets for Australia, with Japan taking some 65% over the whole period. In the PEC-4 run the effects of the exclusion of Japan from the community are noticeable.

Food production plays a major role in the economies of Australia and New Zealand. For both countries the PEC-3 run opens up markets in the developed and developing countries, resulting in the highest production levels over all cases. As the petajoule equivalent of food in Figure 11 shows, a marked increase in quantities produced is apparent. When expressed in dollars these increases appear even greater. It is interesting to note that both countries do increase their production within all of the communities considered here. This leads to the conclusion that both Australia and New Zealand would be competitive in their own right owing, in part, to the complementarity of the type of agricultural commodities each produces – Australia with its wheat and beef and New Zealand with its lamb, cheese, and butter.

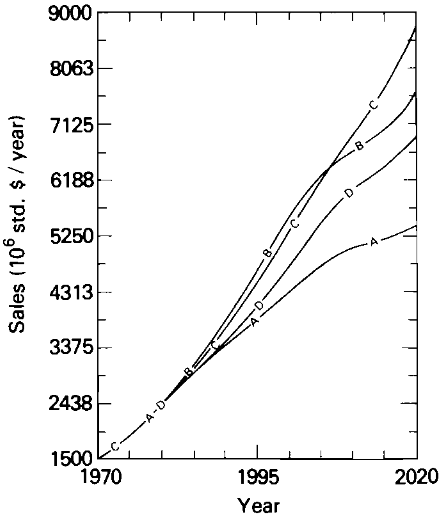


FIGURE 10 Sales of minerals per year by Australia. The curves refer to the following scenarios: A, reference scenario; B, PEC-1C; C, PEC-3; D, PEC-4.

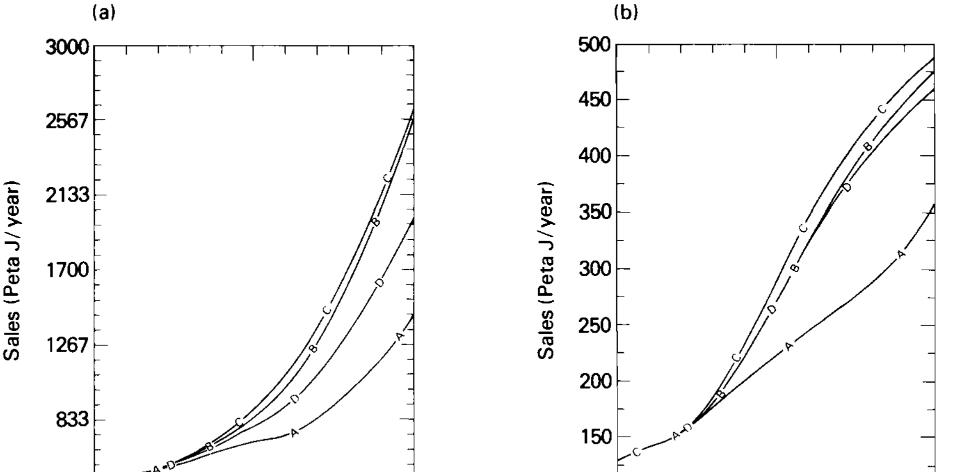


FIGURE 11 Sales of food per year: (a) Australia; (b) New Zealand. The curves refer to the following scenarios: A, reference scenario; B, PEC-1C; C, PEC-3; D, PEC-4.

7 EFFECT OF THE PECs ON TRADING BY AUSTRALIA AND NEW ZEALAND

Trade plays a major role in countries with small domestic markets such as Australia and New Zealand. However, doubts are raised as to whether such small economies can compete amicably with large economies within the context of economic communities. Such communities comprising countries with large and small economies and/or large and small populations may encounter problems arising mainly from the size differences between them. To examine this we now consider the net trade of commodities for Australia and New Zealand.

Of the cases considered here, PEC-1C gives Australia its "best" trade levels. While all four cases show that Australia will be a net exporter of energy, food, and minerals, the ranking of these commodities as to which is the largest by the year 2020 changes for each of the PECs considered. In Figure 12(a) the reference scenario shows energy as yielding the largest net exports, followed by food and minerals. In the cases of the PEC-1C run (Figure 12(b)) and the PEC-3 run (Figure 12(c)), however, the food sector emerges as the major exporter. For PEC-4 we see from Figure 12(d) that energy once again tops the list. From Figures 12(b) and 12(c) we also see that some of the declines shown earlier in the production of energy can be attributed to a falloff in exports of energy. Since these figures show net exports the full impact of the loss of energy exports is not fully described here. Australia's major net import continues to be manufactured goods; this reaches some $35 billion by the year 2020 in the PEC-1C case. This is followed by machinery and natural products. With the access of the domestic market to cheaper manufactured goods, the import of this commodity has detrimental effects on the home industry. Thus, under the assumptions of these cases, it would appear that Australia will remain a primary producer with gains in the output levels generated by the agricultural sector in recent decades resulting from the increasing demand for food following from the increasing wealth of the developing countries in Asia.

New Zealand's net export earners remain the same for all four cases. Food followed by natural products are the main exported commodities. In terms of energy supplies, however, New Zealand moves from being self-sufficient to being a net exporter before swinging downward to the position of a net importer after about 2005. Demands made by its processing and service industries in the PEC-1C case (Figure 13(b)) generate greater energy import requirements than in the reference scenario (Figure 13(a)). This applies to the other cases as well. Although New Zealand can meet its own mineral requirements the demand for imports of machinery and manufactured products is great. This net importing situation is greatest in the PEC-3 case (Figure 13(c)). Using Figure 13(d) we can compare the PEC-4 case with the other cases. In summary, then, New Zealand is also a primary producer for the period of the simulation in all four cases, with energy fluctuating from a situation of net exports to net imports.

Both Australia and New Zealand are endowed with rich natural resources and are well placed to service markets which are less well placed in this respect. Both countries gain appreciably, in the trading sense, from participation in any of the communities considered here. However, when North America is introduced into the community the trade opportunities for these countries are reduced. This arises because North Amercia is well endowed with natural resources similar to those drawn on by Australia and New Zealand. North America thus competes with these countries for the increasingly open markets of

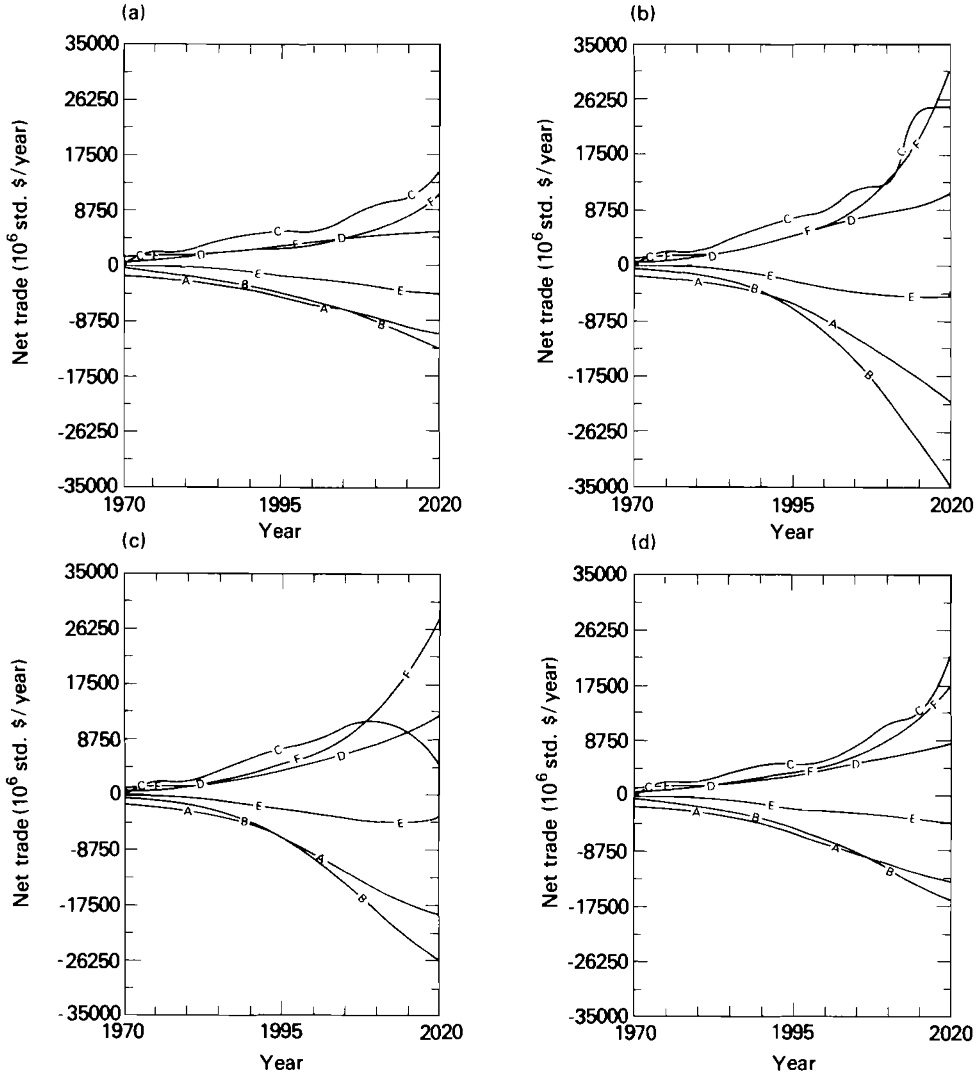


FIGURE 12 Net trade by Australia under different scenarios: (a) reference scenario; (b) PEC-1C; (c) PEC-3; (d) PEC-4. The curves refer to the following categories: A, machinery; B, manufactured goods; C, energy; D, minerals; E, natural products; F, food.

Japan and ESEA. The impact on Australia's and New Zealand's trading prospects caused by the participation of China in the community is not great, despite its considerable reserves of minerals and energy. Japan is shown to be increasing its energy imports from China. In each case the ESEA region remains a big importer of food from Australia and New Zealand. One of the reasons for this could be that the high trade biases operating at the beginning of the simulation period are hampering a rapid incursion of China's

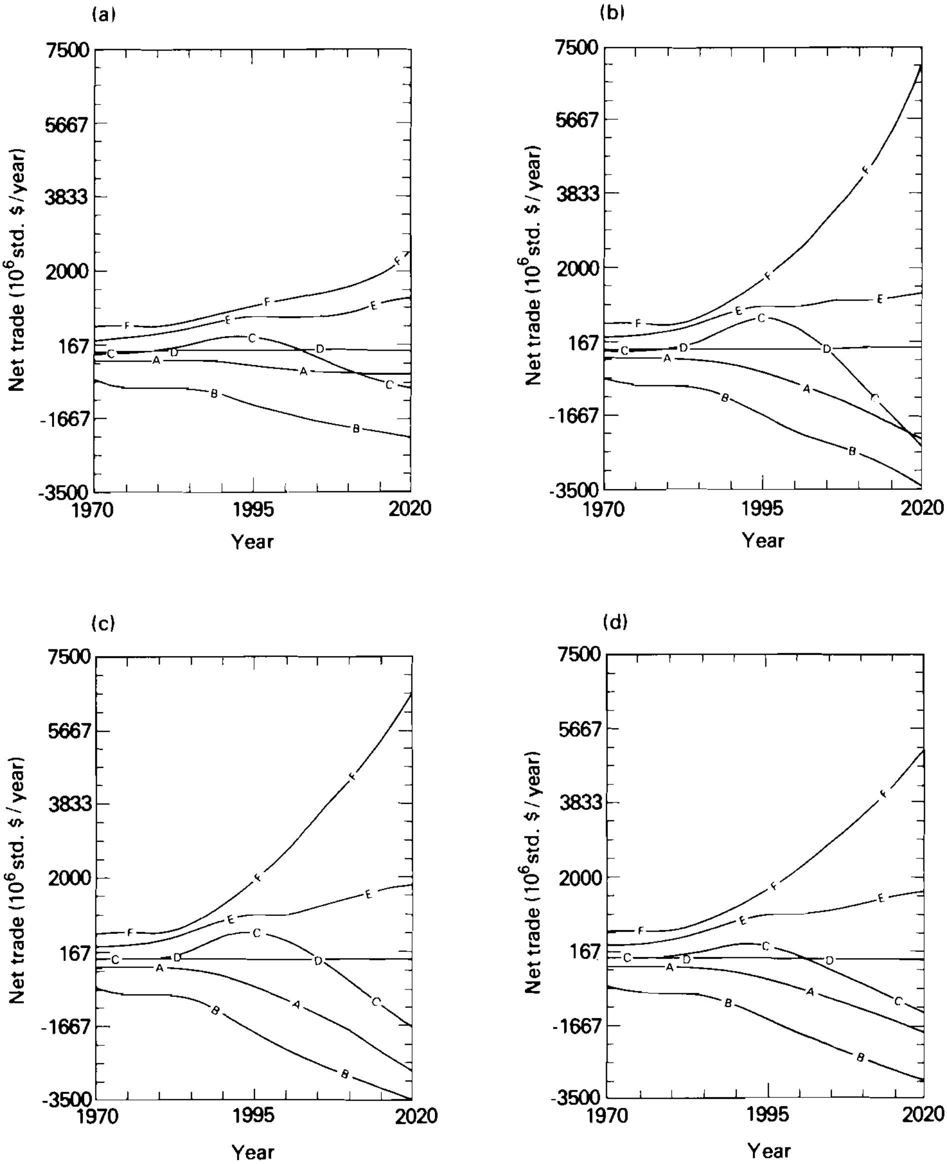


FIGURE 13 Net trade by New Zealand under different scenarios: (a) reference scenario; (b) PEC-1C; (c) PEC-3; (d) PEC-4. The curves refer to the following categories: A, machinery; B, manufactured goods; C, energy; D, minerals; E, natural products; F, food.

commodities into the rest of the Asian region. A more rapid liberalization of trade between China and ESEA and its effects on the other countries would be of interest. In the case of China, however, there are physical and population constraints which would hinder any major export drive, particularly in food.

8 CONCLUSION

In this paper we have shown how global models can enhance the understanding of national issues. The feedback mechanisms mirror the world interdependence of regions. Even at this highly aggregated level we have been able to throw some light, in a systematic and quantitative way, on what until now has been a highly qualitative evaluation of Pacific Economic Communities. However, for a more detailed analysis at the national level we feel that joint investigations involving global and national modeling projects could only enhance the ability of economic models to provide authorative input into policy analysis of the PEC issue.

ACKNOWLEDGMENTS

We would like to acknowledge the invaluable computing contributions to this project made by Dr. Phung Tran and Dr. Brian Boutel.

REFERENCES

Mula, J.M. and MacRae, D. (1979). Global economic modelling: some Australian and New Zealand perspectives. In, Proceedings of the Australia and New Zealand Regional Science Association Conference, 4th, Albury-Wodonga, 1979.

OECD (1979). Facing the future: mastering the probable and managing the unpredictable. Interfutures Final Report. Organization for Economic Cooperation and Development, Paris.

Parker, K.T. (1977). Modeling interregional activity by means of trade biases. In, Proceedings of the IFAC–IFORS–IIASA International Conference on the Modeling and Control of National Economies, 2nd, Vienna. North-Holland, Amsterdam.

DISCUSSION

Asked by Steger, Mula *and* Parker *pointed out some of the difficulties encountered when splitting a national model into regions (for example, in the case of Australia, into New South Wales, Tasmania, etc.). For these regions the balance-of-payments constraints contained in the model do not apply.*

On the suggestion of the Chairman, a general discussion was taken up.

Asked by Driessen, Mesarovic *replied that his model differentiates five different types of land; for each type of land there are two nonlinear relationships one of which relates capitalization and fertilizer as an input equivalent of the second nonlinear relation which relates fertilizer and yield for different types of crops. These relationships must be physical if one talks about a long-term constraint because this is the only way to estimate these nonlinearities. In the new version of the Food and Agricultural Model this will be disaggregated in more detail.*

Mula *asked* Mesarovic *to classify to what extent user's need determined his model. In reply* Mesarovic *stated that different user's needs can be met by different versions of the same model; there is no such thing as* the *model of the real world. Every model is* *designed to answer a specific question or a set of questions. As a modeler one tries to respond to the questions which the user had in mind; however, having his general background, he tries to provide the user with as global a picture as possible (global in both senses: conceptually as well as geographically). If a modeler wishes to analyze one particular sector more deeply this sector must be disaggregated in more detail than would otherwise be meaningful.*

Mula *raised the question why the model did not go any deeper into environmental considerations. Was it because there was no demand from the user's side?* Mesarovic *replied that his model went more deeply into environment than possible users of his model might have demanded; given the overall constraint of manpower and money, however, environment was not treated as thoroughly as he himself would have desired.*

Kamrany *asked whether or not one of the main purposes of a global model is to bring to the attention of the political and economic decision maker possible constraints in the future.*

Mesarovic *stressed that models should not aim at making predictions. They should only be regarded as policy-assessment tools, representing merely one part of the total system needed by the user to look into the future. The other part must be provided by the user himself; it consists of ideological and/or political considerations as well as assumptions about concurrent events. To produce a large number of model runs is only one part of the game; in order to arrive at a consistent scenario alternative policies must be added from outside the model.*

Kamrany *pointed out that many models just project past trends without explicit normative impacts.* Mesarovic *agreed that it is a useful exercise to produce at first such a "standard run" before going into a more detailed analysis. However, to give an example, a goal like the "new economic order" cannot possibly be depicted by such a standard run. A model should tell that if certain changes take place or if certain policies are implemented then these are the likely consequences.*

Steger *raised the question: How can a model be used by a policy maker interactively if the model serves only as one part of the forecasting process?* Mesarovic *replied that it is up to the modeler to explain to the policy maker that what he gets out of an interaction, yielding alternative model results within a few minutes, is only part of his decision basis. Theoretically, political considerations could also be included into the computer model, but this might not render the model more useful for the user.*

GLOBAL STRATEGY FOR DEVELOPMENT: A SHORT INTERIM REPORT ON THE FUGI–ESCAP MODELING PROJECT

Y. Kaya
Faculty of Engineering, University of Tokyo, Tokyo (Japan)

A. Onishi
Faculty of Economics, Soka University, Hachioji, Tokyo (Japan)

1 INTRODUCTION

1.1 Background

In the almost one-third of a century that has passed since World War II, the world economy has experienced remarkable changes, both quantitative and qualitative. The gross world product and world energy consumption have tripled and world cereal production has increased by 2.4 times since 1950. However, it should never be forgotten that the wealth thus accumulated has been distributed remarkably unevenly over the world. For example, the Gross National Product (GNP) of Japan has increased by 14.2 times since 1950 while that of India has been improved only by 2.4 times.

In other words the economic gap between the developed and developing countries, i.e. the so-called North–South gap, has been widening continuously. It is not very difficult to see why this gap, typified by the example of Japan and India, has been widening, since most developed countries have produced industrial goods of high quality at reasonable prices based on cheap primary goods mainly supplied by developing countries which always suffer from the vicious circle of high population growth and economic stagnation.

Since 1970 the demand for greater equity among nations has become dominant in every aspect of international relations, and the adoption of policy measures to accelerate the growth of developing countries has been the main theme of discussions at many international conferences and symposia. Since almost all countries are interwoven in the network of international trade and monetary flows, the development of a developing economy depends not only on the growth of its domestic demand but also on the economic and political behavior of the developed countries. The question then arises whether the developing economy will be able to develop itself, relying solely on the price mechanism of the international economy, and it may be too optimistic to expect a positive answer to this question.

The so-called New International Economic Order declared by the United Nations reflects the need for political action along this line, and we must recognize various elements in the present and future which could hinder the narrowing of the gap between North and South.

1.2 The Oil Crisis

Obviously one of the most serious elements is the energy constraint, both in terms of physical quantity and price. The US Congress reported in April 1979 (see, for example, Nezu, 1979) that future expansion of petroleum production in Saudi Arabia would be limited at maximum to a level of 12 million barrels per day by 1985 or possibly at the present level of 8.5–9.5 million barrels per day, owing to both technical barriers and the policy of the Saudi Arabian government which puts more emphasis on resource conservation than on paying the high cost of further exploitation of the oil fields. Since the increase in petroleum production to meet the increase in world demand has been expected to come mainly from Saudi Arabia, the fear of a future crisis spread worldwide. The agreement on the 1985 target for oil imports made at the Tokyo Summit in June 1979 reflects how seriously decision makers in the developed countries were concerned with the present status of petroleum production. However, it is not solely a problem of the advanced industrialized countries but also of many developing countries, especially Asian ones, which are poor in energy resources and import petroleum. The fact that the demand elasticity of commercial energy – mainly petroleum – with regard to GNP per capita is in most cases higher in developing countries than in developed countries (Pindyck, forthcoming) indicates how essential energy is to the development process.

Another serious factor in energy issues is the steep rise in oil prices, which were around US$12 per barrel only a year and a half ago and are now (October 1979) around US$20 or even more.

The rise in oil prices acts as a main driving force in pushing oil-importing developing countries towards greater foreign-currency deficits, hence decelerating their economic growth since demand for oil is rather insensitive to rises in prices (Pindyck, forthcoming).

One of the key factors in decision making is therefore how to reduce the negative effects of the oil crisis, which may continue for years to come.

1.3 Competition in the World Market

Would the future prospects of developing countries be brilliant if the oil crisis did not exist? Not necessarily, for the gap between developed and developing countries might continue to widen since there are still many other elements acting as constraints that hinder the development of their economies. Competition in the world market for industrial goods has been one of these elements. It may exert heavy pressure on developing countries unless some drastic change occurs in the industrial structure of developed countries. Almost all developed countries have achieved their progress on the basis of industrial production and the export of industrial goods to developing countries. The recent rapid growth of Newly Industrializing Countries (NICs) has had a remarkable effect on the industrial production of developed countries as competitors in the world market for industrial goods.

Since Asian NICs such as South Korea, Hong Kong, and Singapore are poor in energy and mineral resources they have to rely mainly on industrial production, while almost all developed countries are, and would prefer to stay, in the position of net exporters of industrial goods. This indicates that severe competition in the world market will be unavoidable regardless of whether developed countries put emphasis on knowledge-intensive industries and developing countries on labor-intensive industries. It is very important to find out how and to what degrees NICs will be able to develop themselves in spite of this barrier.

2 GLOBAL MODELS AND PROJECT FUGI

2.1 First-Generation Models

The issues discussed in Section 1 are essentially international and long range in character and need to be examined in the light of quantitative analysis, which inevitably requires the building of a model of global scale.

Among the early work in this field is the well-known Limits to Growth Model of the Massachussets Institute of Technology (Meadows et al., 1972); this was a milestone in the study of global modeling as it put stress on the importance of interlinkage between various global issues and raised the alarm about the consequences of unrestrained development of modern civilization. However, this model possesses several defects, of which the most serious is that the world is treated as a whole. In other words differences between regions or countries in the world are completely neglected so that international issues such as the North–South gap cannot be examined.

The Latin American World Model developed by the group at the Fundacion Bariloche (Herrera et al., 1976) tried to overcome this defect by dividing the world into four regions, of which three belong to the developing world. This model holds a rather unique position in the history of global modeling as the modelers preference for socialism is built into the model in a very transparent manner. According to the research report, stagnation of the Latin American economy has been mainly due to sociopolitical inefficiency. Implementation of the appropriate socialist policy measures may allow the self-reliant development of Latin America to be realized, whereas foreign aid is indispensable for the development of Asian and African developing countries for at least ten years to come because of the higher cost of exploiting their natural resources. Although the background concept, the structure, and the purpose of the Latin American World Model are far different from those of the Limits to Growth model, the two models are similar in that each is used to support a certain assertion, which may be presented even without the use of models.

2.2 Second-Generation Models

If the previous two models may be called the first-generation models, the second-generation models are those that are being used or are to be used as more concrete tools in both international and national policy making. The Leontief UN model (Leontief, 1976), the Systems Analysis Research Unit Model (SARUM) (Roberts et al., 1976), our FUture of Global Interdependence (FUGI) model, and the models that are being built in various international organizations such as the Food and Agricultural Organization, the UN Industrial Development Organization (UNIDO), the UN Conference on Trade and Development (UNCTAD), and the World Bank are typical examples.

The basic objective of models of this kind is to establish a tool to envisage future scenarios of development of the world economy in a comprehensive way in which population, resources, and environment can be treated as endogeneous factors. The models are required to be operational enough to develop scenarios corresponding to different choices of policy parameters or variables and to be reliable enough to produce detailed information on the future economy without losing consistency with the past data. The Mesarovic–Pestel model (Mesarovic and Pestel, 1974) has in our opinion characteristics of both the first- and the second-generation models.

2.3 The FUGI Model

Project FUGI was launched with the authors as coleaders in 1976 under the sponsorship of the Japan Committee of the Club of Rome and the Japan National Institute for Research Advancement. The first research report (Kaya et al., 1980) was presented at the Fifth IIASA Global Modeling Conference 1977 and the second report (Kaya et al., 1979) was presented jointly with two researchers from the UN Economic and Social Commission for Asia and the Pacific (ESCAP) at the Seventh World Congress on Input–Output Techniques in April 1979.

The FUGI model is essentially a combination of two models; a dynamic Global MacroEconomic Model (GMEM) and a static Global Input–Output Model (GIOM). The GMEM determines the growth path of the world economy, region by region, given a certain set of policy and other exogenous parameters, and the GIOM determines the possible industrial structure (14 sectors) of each region within the macroeconomic framework given by the GMEM.

Since 1978 we have been in close collaboration with the UN ESCAP Office in connection with the investigation of the future possibilities for development in this area. Some of the computational results will be shown later in this paper.

We are also promoting collaborative studies with other institutions such as the Indonesian Academy of Sciences under the sponsorship of the Japan Society for the Promotion of Science and the Free University of the Netherlands, with the firm belief that such collaboration will help all the researchers concerned to elaborate models and thus deepen insights into the problems we are facing.

3 SCENARIOS OF DEVELOPMENT

Various issues in the development of the future world economy that have been investigated by the use of the FUGI model will be described in this section.

3.1 Macroscopic Patterns of Development and the Effect of Rises in Oil Prices

The standard scenario which we consider first is concerned with the question of what, up to the year 1990, will be the patterns of population and economic growth in the various parts of the world and just what will happen to the economic gap between North and South. The resultant forecast obtained from the GMEM envisages a tendency for the tempo of economic growth in the industrially advanced regions (including Japan) to fall somewhat and for the tempo of economic growth in the developing regions to rise somewhat; nevertheless, the gap in per capita incomes will probably continue to widen. (One projection of the North–South gap in per capita income* is as follows: in 1975 US dollars. 11.0:1 in 1970; 10.8:1 in 1980; 10.4:1 in 1990.) It is likely that income inequalities in our global society will increase and that there will in the future be a tendency toward even sharper opposition between North and South.

Second, we ask whether, under the supposition of a further widening in the income and technology gap between the North and South economies, policies can be designed to diminish this gap. In this connection, if the industrially advanced regions slow down their rates of growth what sorts of impacts will this have on economic development in the developing regions? Our forecast is that, so long as there is no change in the structure of the present world economic system centered on the industrially advanced countries, a lowering of the tempo of economic growth in the industrially advanced regions is likely to cause a lowering of the tempo of economic development in the developing regions, which have strong links with the industrialized regions, especially through trade and official development assistance. Thus, so long as the present mechanisms of world industry and trade move according to the patterns seen hitherto it may be assumed that zero growth in the industrially advanced regions will not contribute to diminishing of the North–South gap but will only have the effect of tending to freeze and perpetuate the present state of inequality.

Third, in relation to the building of a new international economic order for the 21st century, and assuming a more equitable distribution of natural resources among the various regions of global society, we ask the following question: if it were possible, in conjunction with a slowdown in the tempo of economic growth in the industrially advanced countries, to increase greatly the flow of funds (official development assistance, private foreign investment, etc.) to the developing regions, could such a process contribute to diminishing the North–South gap? Of course, unless the additional flow of funds from the industrially advanced to the developing regions were greater than the export reductions in the developing regions the tempo of economic development in the developing regions would not be expected to rise. According to the forecasts derived from the GMEM, if the rates of economic growth in the industrially advanced regions were cut by energy constraints it would be necessary to raise the official development assistance given by these regions considerably above present levels in order to avoid a lowering of growth rates in the developing regions. In such a case the balance of trade of the industrially advanced regions with respect to the developing regions would tend to take a favorable turn.

Fourth, in the process of restructuring North–South economic relations within a new international economic order it is necessary that the transition of the developing regions to industrialized societies should be encouraged; however, at the same time we

---

* Taking the average per capita income for the developing South as unity throughout.

must ask what the various impacts of this industrialization will be and what will be the response of the industrially advanced regions. The transition of developing countries to industrialized societies does not necessarily mean their following in the footsteps of today's major industrially advanced countries, along a path of industrialization characterized by "overconsumption" of energy resources. As for the policy response of the industrially advanced regions, it is obviously necessary that from a viewpoint favoring more equitable use of the earth's resources there must be a change from patterns of overconsumption to an economic system characterized by energy and resource conservation. One may even say that it is desirable, for the purposes of encouraging recycling and the control of energy and resource overconsumption, that the prices of primary resources such as oil and industrial raw materials should be maintained somewhat on the high side. However, there are of course fears that increases in resource prices may accelerate world inflation. We have attempted to analyze this problem using the GMEM.

According to the results calculated from the model, as long as resource prices do not go beyond certain limits of expansion which allow for effective policy response they do not appear likely to become an important factor which would accelerate world inflation.

While rises in resource prices may or may not, then, be a major problem, one can definitely say that inflation is very largely the result of factors in market economies such as wage costs, pressures from demand, and imbalances in international trade and monetary flows. From the GMEM computations it is seen that if we can succeed in controlling these factors in a systematic way it is not impossible that moderate rises in resource prices can be absorbed within plans for overall stabilization of commodity prices.

Fifth, in regard to the stabilization of primary-commodity prices, the GMEM may be used to study scientifically questions such as buffer stocks and indexation with respect to the export prices of manufactured goods from the advanced market economies.

With regard to commodities given primary attention by UNCTAD (tea, coffee, cocoa, sugar, copra, cotton, jute, sisal, tin, copper, etc.), we found that movements in the prices of these primary commodities are linked most particularly to increases or decreases in stock and to movements in wholesale prices in the industrially advanced countries which are themselves greatly influenced by US prices. One can say that primary commodity prices are, under the present international economic order, already in effect linked with export prices in advanced market economies. This means that so long as US wholesale prices remain unstable it will be difficult to stabilize primary-commodity prices by means of buffer stocks. The forecasts of the GMEM also show that if wholesale prices in the major industrially advanced market economies (and especially in the United States) can be stabilized then the stabilization of primary-commodity prices through buffer stocks may be possible.

This means that a precondition of stabilizing primary-commodity prices – one of the most important problems for a new international economic order – is that countries with advanced market economies must achieve more success in stabilizing wholesale prices and fluctuations in business climate.

Through studies of questions such as the foregoing the following conclusions may be drawn from the GMEM. What is essential in the short and medium term is that the developing countries should have greater purchasing power to help them to establish themselves more squarely on a developmental course. Keynes once argued in favor of a policy of creating more effective demand on a single-country level as a measure for dealing with economic slump in the industrially advanced countries. In today's global society, however, measures for dealing with economic slumps in the industrially advanced countries cannot be discussed without considering their interdependence with the developing countries. Also, looking at this problem from a global point of view, the mutual adjustment of economic policies and the maintenance of moderate economic growth on the part of the industrially advanced countries is a precondition for imparting greater purchasing power to the developing countries. Going beyond this, dynamic international arrangements must be established whereby the production and levels of purchasing power of the developing countries can be raised through such means as technology transfers, rules and regulations on the conduct of multinational corporations to help ensure that their operations will be of positive value, increases in development aid, and stabilization of primary-commodity prices.

3.2 Industrialization in Asian Countries

Industrialization is considered as an indispensable step in the development process. The Declaration and Plan of Action resulting from the UNIDO Conference held in Lima in 1975 called for the share of developing market-economy countries in the world manufacturing industries to expand from 7% in 1970 to 25% by the year 2000.

The need to promote industrialization is more pressing in most Asian developing countries as they have huge populations and have to import energy resources. The balance of international trade in these countries requires the export of industrial goods rather than primary goods because of the high marginal production cost due to exploitation of limited physical resources. South Korea, Taiwan, Hong Kong, and Singapore are already tracing this growth path, which is, however, considered as a serious threat to present developed countries such as the United States and Canada. (The term "new Japan" is used for these countries in the US Congress report on Japan–USA trade published in April 1979.) This section investigates what degree, and what kind of, industrialization is feasible for Asian developing countries, various socioeconomic constraints being taken into account.

The GIOM is employed for this purpose. Given the framework of the macroeconomy in a specified year (in ordinary cases 1985 and 1990) from the GMEM, the GIOM yields the sectoral production, exports, and imports of each region in the world. The model also employs the optimization method, through which it yields scenarios which are extreme in the sense that some chosen criteria are maximized within the constraints. The constraints include those on the supply–demand balance of the goods in each sector in the world, on the upper and lower bounds of exports and imports (the maximum difference from the regressed estimate is given), on the maximum changeability of the industrial structure, etc. If, for instance, the modeler wishes to see the maximum level of industrialization of the Asian developing region then the criterion function is chosen as the sum of the products of value added in the manufacturing sectors of the countries belonging to the Asian developing region.

Two macroeconomic cases are adopted as frameworks, namely cases A and B as shown in Table 1. Case A may be called the standard scenario in which the oil price changes in parallel with the prices of exports from developed countries. Case B may be

TABLE 1 Gross regional products (in billions of US dollars at 1970 prices) and annual percentage growth rates (in parentheses) for the 14 regions in the FUGI model.

Region	Case A		Case B	
	1985	1990	1985	1990
1 USA, Canada	1780.40 (4.0)	2162.49 (4.0)	1776.04 (4.0)	2190.21 (4.3)
2 EEC[a], other developed countries	1382.30 (4.1)	1713.63 (4.4)	1372.78 (3.9)	1730.01 (4.7)
3 Middle East	136.92 (8.1)	202.86 (8.2)	154.33 (10.8)	269.92 (11.8)
4 Latin America, Africa	473.06 (5.6)	619.21 (5.5)	491.02 (6.4)	670.72 (6.4)
5 Japan	447.50 (6.0)	612.24 (6.5)	454.94 (6.4)	644.06 (7.2)
6 Oceania	74.70 (3.5)	93.54 (4.6)	74.20 (3.3)	95.61 (5.2)
7 India	83.32 (3.4)	98.47 (3.4)	91.25 (5.3)	116.17 (4.9)
8 South Korea	34.68 (9.5)	53.33 (9.0)	40.77 (13.1)	71.95 (12.0)
9 Taiwan, Hong Kong, Macao	26.64 (6.8)	36.43 (6.5)	27.54 (7.5)	38.52 (6.9)
10 Indonesia	23.29 (5.7)	31.37 (6.1)	25.27 (7.5)	38.11 (8.6)
11 Malaya, Singapore, Thailand	34.93 (6.8)	48.12 (6.6)	37.36 (8.2)	55.00 (8.0)
12 Philippines	20.38 (8.3)	30.62 (8.5)	20.15 (8.0)	31.62 (9.4)
13 Other Asian countries	48.82 (3.1)	56.99 (3.1)	54.59 (5.4)	73.66 (6.2)
14 Centrally planned economies (Europe)	1018.19 (5.2)	1311.26 (5.2)	1018.19 (5.2)	1311.26 (5.2)

[a] EEC, European Economic Community.

called the optimistic case in which official development assistance attains the level of 0.7% of the GNP of the developed countries and the elasticity of total exports of developing countries with regard to the GNP of importing countries is increased by 10%.

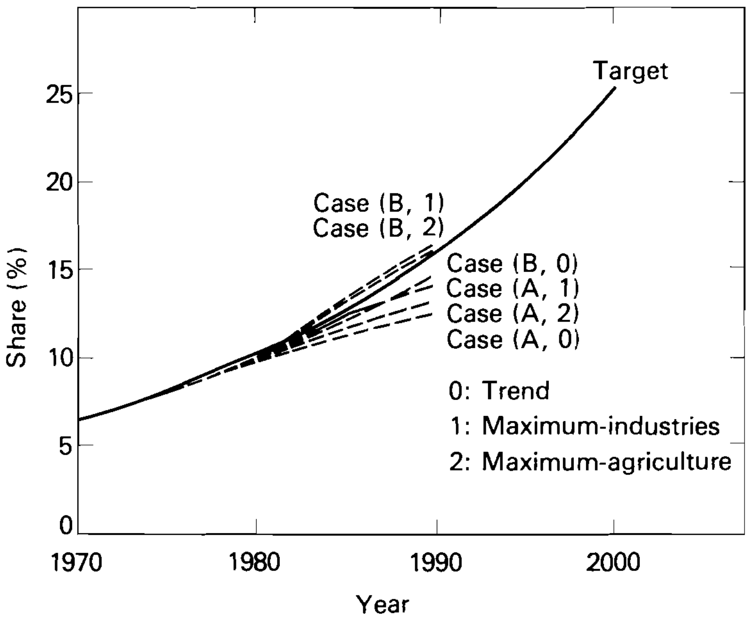


FIGURE 1 The Lima target for the share of developing market-economy countries in world manufacturing industries, and the extent to which it is met under various scenarios.

Given either case A or case B, various types of detailed scenario are then constructed through the use of the GIOM. It is most interesting to observe the level of industrialization in different scenarios (Figure 1). It is clear that the level exceeds the Lima target translated for the year 1990 (it is assumed that the industrialization will proceed at the same rate after 1990 as before 1990) only in case B, but in two scenarios: the maximum-industry scenario and the maximum-agriculture scenario. In the former scenario maximum efforts are focused on industrial production while in the latter maximum efforts are focused on agricultural production, which stimulates industrial production through forward linkage paths.

The maximum-agriculture scenario shows the usefulness of agriculture-oriented development even in Asian developing countries with scarce resources. The agriculture-oriented development is a smooth path towards industrialization from agriculture to light industry and then to heavy industry. In contrast, the maximum-industry scenario involves industrialization of a rather undesirable type in which heavy industrial production is substituted directly for agricultural production. Consequently agricultural production will grow too slowly (see Figure 2) to meet increasing demands due to population increase and higher income.

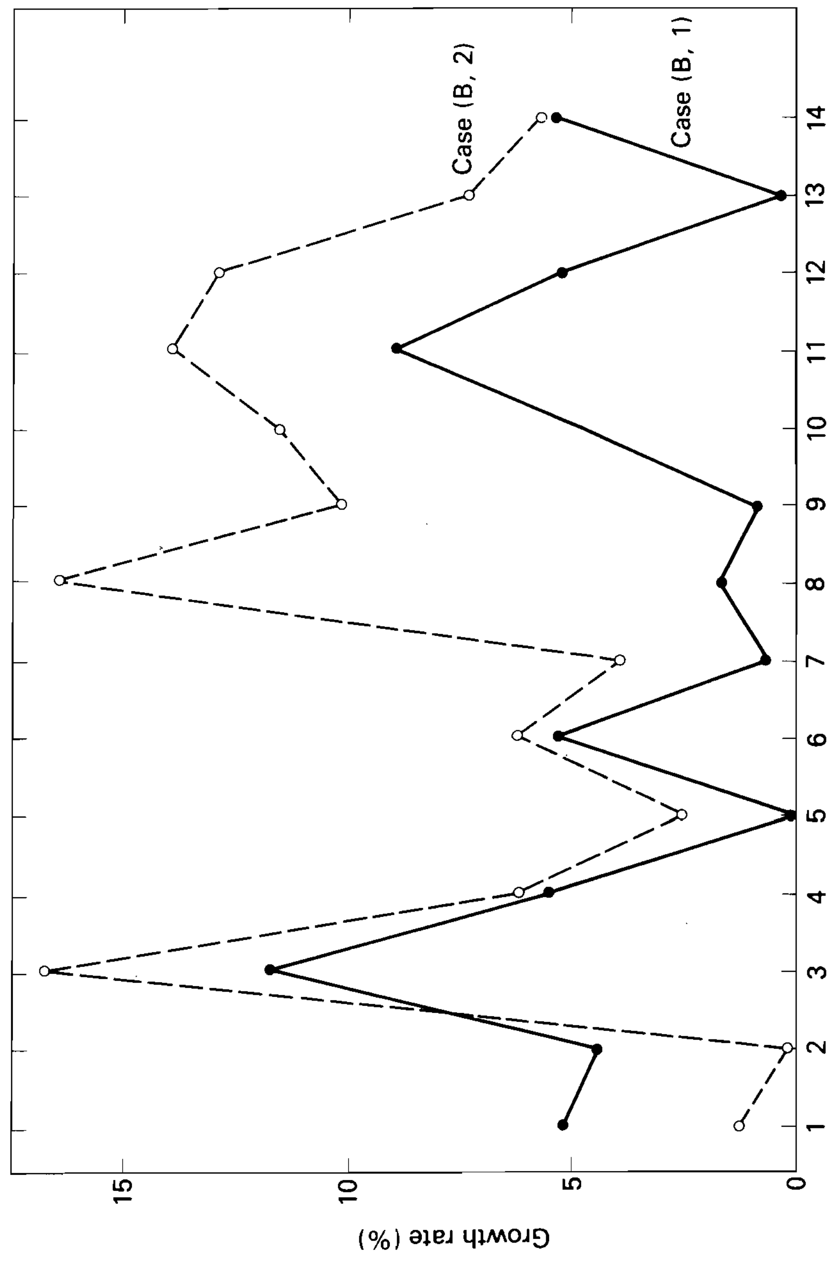


FIGURE 2 Growth rate of value added (1970 prices) in agriculture, 1985–1990, for the 14 regions considered in the FUGI model. (The regions are numbered 1–14 as in Tables 1 and 2.)

TABLE 2 Average percentage growth rates of gross regional product (GRP) and manufacturing industry for the 14 regions in the FUGI model (case (A, 0) in 1985 to cases (B, 1) and (B, 2) in 1990, in 1970 prices).

Region	GRP	Manufacturing industry	
		Case (B, 1)	Case (B, 2)
1 USA, Canada	4.2	2.9	2.4
2 EEC[a], other developed countries	4.6	2.6	3.2
3 Middle East	14.5	16.7	20.1
4 Latin America, Africa	7.2	11.1	11.1
5 Japan	7.6	7.5	7.5
6 Oceania	5.1	3.4	1.7
7 India	6.9	11.8	10.0
8 South Korea	15.7	19.1	16.9
9 Taiwan, Hong Kong, Macao	7.7	10.7	8.3
10 Indonesia	10.4	18.6	10.7
11 Malaya, Singapore, Thailand	9.5	15.8	10.4
12 Philippines	9.2	14.1	10.0
13 Other Asian countries	8.6	14.6	11.7
14 Centrally planned economies (Europe)	5.2	4.2	4.1
15 Developed countries, average	4.9	3.7	3.7
16 ESCAP less developed countries, average	9.3	14.7	11.6

[a] EEC, European Economic Community.

As for the Lima target, the growth rates of industrial production of different regions in the world are shown in comparison with the growth rates of Gross Regional Product (GRP) in Table 2. It can be seen that the rate of industrialization required for the Lima target is extremely high. In other words realization of the Lima target requires a drastic change in the efforts of the developed countries to expand their imports of industrial goods from the developing countries as well as to increase official development assistance.

In any case, more attention should be paid to the result that agricultural development in Asian countries will be efficient not only in reducing variability of the food supply in these countries but also in promoting industrialization. Heavy-industry-oriented development as in India may not be the wisest way for Asian developing countries.

4 CONCLUSION

Throughout this investigation of the various scenarios developed by the FUGI model a more rational international division of labor among the industrially advanced and the developing countries has been again stressed. At present the industrially advanced countries have a comparative advantage in the export of goods and services that are relatively knowledge-intensive while the developing countries tend to have a comparative advantage in the export of labor-intensive goods and services. We suggest that changes in the present North–South industrial and trade structures should take into account and follow this kind of pattern, although this may be impossible to realize without changes in present-day human values and in economic and social systems. These questions are thus related to the long-range course of development for global society.

The principle that has up to now been dominant in the world economy has basically been, one might say, the principle of "survival of the fittest". In the coming age of deepening global constraints one must ask whether human society can survive at all with a continuation of such behavior.

Without a change from the traditional principle of "survival of the fittest" to the principles of international cooperation and human solidarity or without changes from systems of wholly unrestrained free competition to systems incorporating a greater element of planning and coordination it will probably be extremely difficult to overcome the various conflicts which we face in the world economy, to guarantee each country's economic security, and to plan for a higher degree of social welfare.

REFERENCES

Herrera, A., et al. (1976). Latin American World Model. Editorial Paidós, Argentina.

Kaya, Y., Onishi, A., et al. (1979). Long-term projection of economic growth in ESCAP member countries. In, the Proceedings of the World Congress on Input–Output Techniques, 7th, Innsbruck, April 1979.

Kaya, Y., Onishi, A., Ishitani, H., Ishikawa, M., Suzuki, Y., and Shoji, K. (1980). FUGI – Future of Global Interdependence. In G. Bruckmann (Editor), Input–Output Approaches in Global Modeling. IIASA Proceedings Series, Vol. 9. Pergamon Press, Oxford, pp. 91–357.

Leontief, W. (1976). The Future of the World Economy. United Nations, New York.

Meadows, D., et al. (1972). The Limits to Growth. Universe Books, New York.

Mesarovic, M. and Pestel, E. (1974). Mankind at the Turning Point. E.P. Dutton/Readers Digest Press, New York.

Nezu, M. (1979). On the Congress report on the future of petroleum production in Saudi Arabia. Energy Economics (Japan), 5(4): 19–26.

Pindyck, R.S. (forthcoming). The Structure of World Energy Demand. MIT Press, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Roberts, P.C., Norse, D., Phillips, W.G.B., Jones, J.B., Parker, K.T., and Goodfellow, M.R. (1978). The SARU Model 1976. In G. Bruckmann (Editor), SARUM and MRI: Description and Comparison of a World Model and a National Model. IIASA Proceedings Series, Vol. 2. Pergamon Press, Oxford, pp. 9–39.

DISCUSSION

Mula *asked* Kaya *to clarify to what extent substitution effects are being considered in his model with regard to the input–output coefficients and/or production functions used. In reply* Kaya *pointed out that the main problem lies in the lack of reliable data for sectoral production functions. If such data are available it is not so difficult to incorporate them into the input–output model. If, for instance, the energy price rises this will change the relative input–output coefficients.* Kaya *said his group is now working on these questions, for example, by constructing a production function for the energy sector for developed countries and, if possible, also for developing countries.*

Steger *expressed doubts whether such data would become available soon. It might be more advisable to use existing micromodels of industry and the commercial use of* *energy. Even if such a model may exist only for one particular country, the relations derived can pretty well be assumed to hold also for other industrialized nations using the same technologies.*

In answer to Mula, Kaya *replied that the economic growth rates are arrived at endogenously in the macroeconomic model which is used as a framework for the (static) input–output model. The growth rates of the developing countries depend, within the model, also on the growth rates of the developed countries.*

TREATMENT OF THE ENVIRONMENT IN GLOBAL MODELS

Jennifer M. Robinson
Fog's Edge Research, P.O. Box 330, Inverness, California 94937 (USA)

1 INTRODUCTION

An academic would begin this paper by defining environment and establishing a set of global models according to some sampling criteria. Here formalities of definition and sample selection are evaded by simply observing how five well-known models treat eight of the matters which environmentalists often talk about. These observations are then used to draw some conclusions about trends in the treatment of the environment in global modeling and to evaluate which aspects of environment have been overemphasized and which have been inadequately treated.

Both the choice of models and the choice of environmental aspects derive from work that I did for the Global 2000 Study, a study of global trends in population, resources, and environment commissioned by US President Carter. Further discussion of both the models and the environmental aspects covered are found in the volumes produced in that study (Barney et al., 1979). The five models are given in Table 1.

TABLE 1 The five models discussed.

Model	Modelers
World 2; World 3	Forrester; Meadows et al.
World Integrated Model (WIM)	Mesarovic, Pestel et al.
Latin American World Model (Bariloche)	Hererra et al.
United Nations (UN) World Model	Leontief, Carter et al.
Model Of International Relations in Agriculture (MOIRA 1)	Linnemann et al.

Omission from the list of models such as the Systems Analysis Research Unit Model (SARUM), the FUture of Global Interdependence (FUGI) model, and others is the unfortunate consequence of attempts to keep from falling too far behind study deadlines with Global 2000 and should not be interpreted as meaning that the excluded models are less important or less interesting than the included models. Nonetheless, five models will suffice to display some general trends in global modelers' treatment of environment. I do not think that adding another dozen models to the study set would alter the general conclusions.

The need for brevity constrains the number of aspects of the environment that can be discussed. Another person would develop a different list and five years hence my own list will probably have changed. However, the following list should serve as a sampler of the broad class of dissimilar problematic entities that are aggregated in public discussions under the term "environment".

(1) Deforestation: particularly in the tropics, particularly as affecting the lives of a billion or more people by destabilizing their water supplies, making fuel scarce, and leading to siltation and erosion; also as an important sink for and source of CO_2.

(2) Soil degradation: particularly as affecting crop yields and quality of pasture, and including problems of salinization, erosion, compaction, leaching, and toxification by human activities.

(3) Climatic change: both anthropomorphic, through released CO_2, particulates, and waste heat and through alteration of reflectivity and evapotranspiration, and natural through events such as volcanic eruptions.

(4) Depletion of fuel and nonfuel reserves: particularly as affecting economic systems; also as disrupting and polluting the earth's surface.

(5) Human services: the provision of clean water, basic food, fuel, and shelter, and other necessities to the world's people, the maintaining of habitable cities, and the provision of services to the rural poor (a concern in its own right); also as a set of factors influencing demographic behavior.

(6) Toxic substances and pollutants: including both abundant pollutants like organic refuse, sulfur, and nitrous oxides and rare highly toxic substances such as complex stable organics and nuclear wastes, which pose long-term threats to human and ecosystem health.

(7) Genetic diversity and genetic resistance: the loss of species, the narrowing of gene pools, and the development of pesticide resistance and antibiotic resistance by unwanted species leading to increased crop losses and resurgences of diseases such as malaria.

(8) Oceans: overfishing, the development of tidal estuaries, and possible pollution as leading to decreased fish yields.

Of course one is interested not only in what is included in models but also in how it is included: in the mechanisms used to represent environmental behavior, in the levels of aggregation used, in the feedback assumed from environment to societies and economies, and in the values used for key parameters. The five models will be examined in turn; the mechanisms and levels of aggregation will be discussed briefly and the parameters not at all. To facilitate comparison each model's content area will be mapped onto a diagram like that shown in Figure 1 and annotated to show the levels of disaggregation and the variables included as linkages between environmental factors.

2 WORLD 2 AND WORLD 3

World 2 and World 3 are both highly developed carrying-capacity models looking at the growth of a man–machine symbiotic system within the material confines of the planet. The system posed by the models of Forrester and Meadows et al. represents the

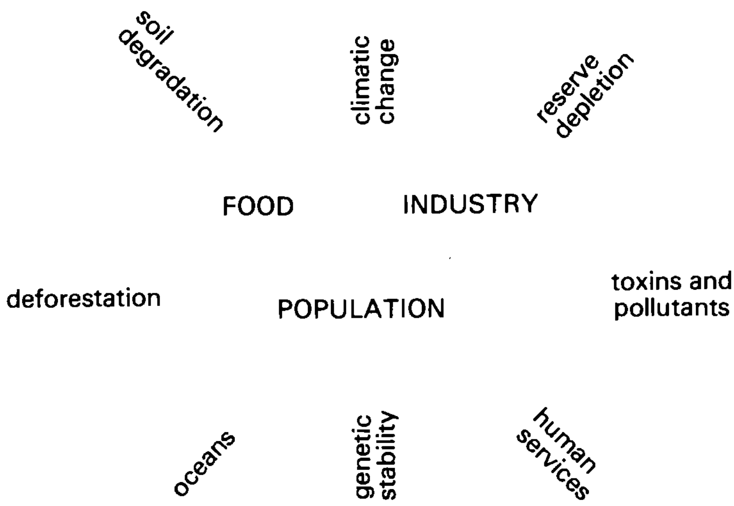


FIGURE 1 Environmental aspects.

environment as a system of variable constraints on the growth of the man–machine symbiosis. Food constrains human population growth. The ability to produce food is enhanced by machines and is decreased by soil degradation. The availability of nonfuel minerals constrains the industrial-machine system. The availability of industrial products and services decreases both fertility and mortality and thus affects population growth. Industrial processes and human activities cause pollution, which in extreme cases may lead to increased mortality.

The total system includes endogenously many of the major aspects of environment (see Figure 2). Only climatic change, genetic stability, oceans, and deforestation are excluded; even deforestation can be considered as implicit in the model's representation of the linkages between food-system growth and soil productivity. However, World 2 and World 3 do not disaggregate the globe and they include many environmental relationships in very simplified fashions, which has made their description of the global ecosystem unsatisfactory to many environmentalists and ecologists.

In simulation World 2 and World 3 generally show an increase in food and income per capita up until 2020, at which time either resource depletion or food scarcity (which comes first is parameter sensitive) sets the system into a downturn. Pollution is an important constraint only when effective constraints on food and industrial development are removed.

3 THE WORLD INTEGRATED MODEL (WIM)

Describing the WIM is notoriously difficult because there are many versions of the model. In the present discourse this is particularly confusing because both the level of aggregation and the treatment of environment vary from one version to the next. In

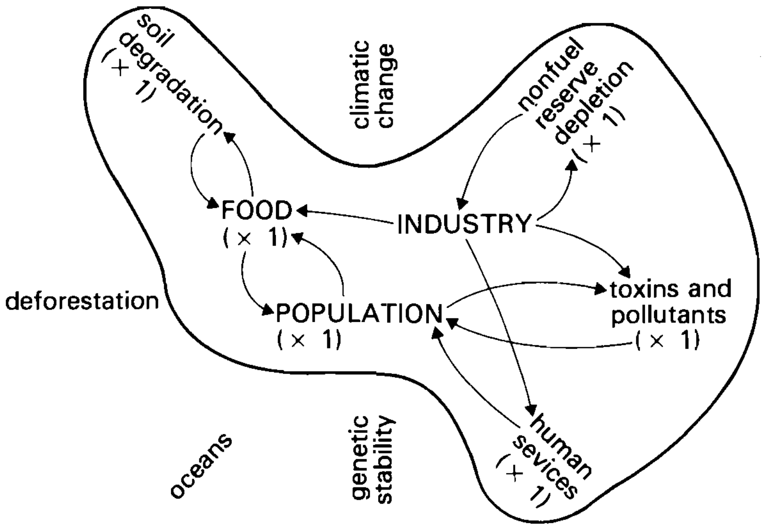


FIGURE 2 Environmental aspects covered in World 2 and World 3.

Figure 3 the matter of disaggregation is treated by labeling matrices as N-regional and specifying representative numbers for the dimensionality of other variables. It should be understood that boundaries are vague (some versions of the model do not include all the factors that the figure describes as exogenous or endogenous, and what is endogenous in one version may be exogenous in another).

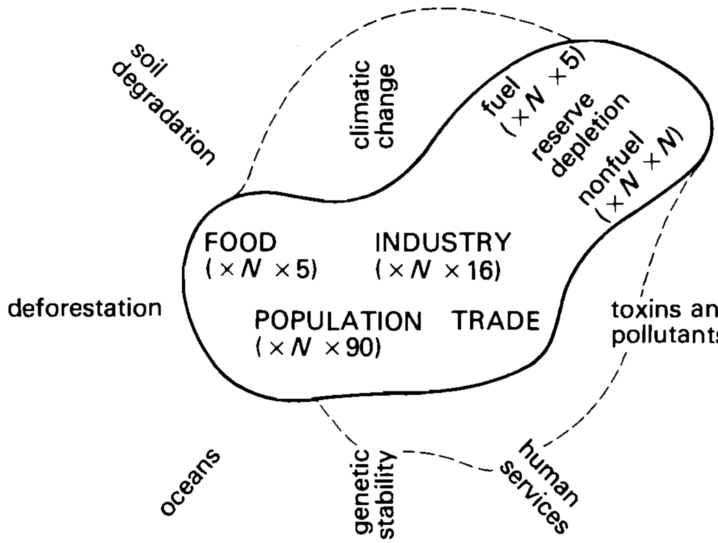


FIGURE 3 Environmental aspects covered in the WIM (———, endogenous; – – – –, exogenous).

In general the WIM can be viewed as the product of replicating a structure similar to World 2 or World 3 eight or more times, parameterizing it to fit eight or more regions, and linking the regions with a trade matrix. In the process many environmental processes, including pollution and soil-degradation feedback processes and usually feedback from food deficiency to mortality, were omitted. Meanwhile attention was shifted from non-fuel to fuel reserves and several variables, including population cohorts, energy sources, industrial sectors, and land classes, were disaggregated. In some uses of the model assumptions about unusually bad weather or climatic change, poor performance in agriculture, toxicity, and the effects of human services on demographic variables have been or could be introduced through scenario construction. Indexes of the generation of CO_2, pollutants, and other environmental factors can also be created within the model as the user desires.

4 THE LATIN AMERICAN WORLD MODEL

World 2, World 3, and the WIM all approach the future deterministically. They ask, so to speak, "What will the world be like two or ten decades from now given the forces at play?" The Latin American World Model shifts to the idealistic question, "How can global resources best be used to meet basic human needs for all people?" The structural framework in which this question is investigated is utopian; the model allocates capital and labor in the fashion that maximizes life expectancy at birth. It assumes a wise non-exploitive society that avoids problems of soil depletion, pollution, and other forms of environmental degradation.

Despite dismissing environmental problems as inconsequential in utopia, the model focuses heavily on the human-services environment as a factor determining the life expectancy. Indeed, the model appears to be dominated by the influence of education, housing, urbanization, and food availability on demographic variables. In this fashion it gives much greater attention to the human-services environment than any of the other models considered here (see Figure 4).

The simulation results from the Latin American World Model are other than what the modelers expected and quite consistent with the findings of other models. Asia and, in some simulations, Africa prove unable, even with very high (25%) levels of investment, to meet food needs. This leads to economic collapse and degeneration of basic-needs fulfillment in the first half of the 21st century.

5 THE UN WORLD MODEL

The UN world model uses a regionally disaggregated input–output approach. It differs from the previously considered models in two respects. First, it is totally linear and contains no feedback; it merely transforms a set of projections of regional gross domestic product, population, and productivity growth into self-consistent projections of mineral usage, pollution-abatement costs, and intersectoral and trade flows. Second, it is relatively short term: projections are made only to the year 2000 (20 years before resource problems appear in World 2 or World 3). It also stands apart in that it includes

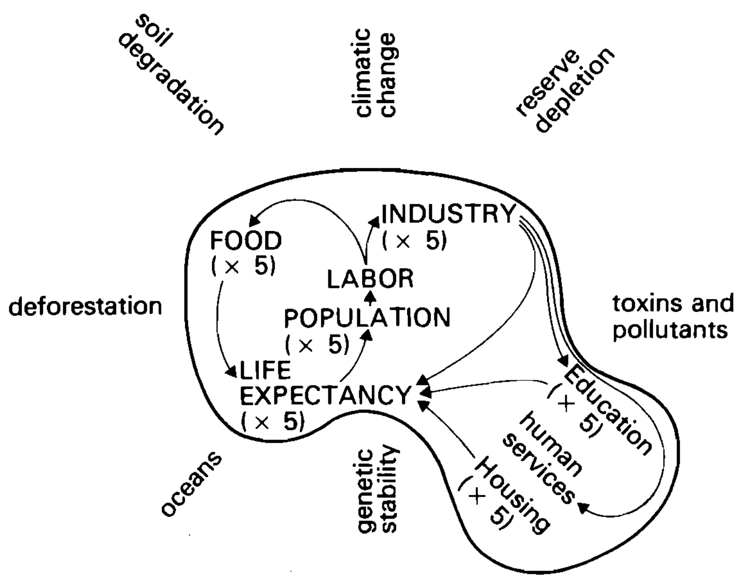


FIGURE 4 Environmental aspects covered in the Latin American World Model.

a large amount of sectoral detail; 40 sectors are included for each of 15 regions (see Figure 5).

The model showed that the attaining of UN targets would require large sacrifices in personal consumption in the less developed countries and very rapid growth of agricultural output. It also showed that the economic costs of controlling pollution were not unbearable; fairly stringent standards could be maintained with an expenditure of less than 2% gross regional product.

Anne Carter, one of the model's primary developers, stated at the Sixth IIASA Global Modeling Conference that she would not recommend use of the UN World Model approach in considering environmental questions because the approach showed environment to be unimportant – something that she believes to be untrue.

6 MODEL OF INTERNATIONAL RELATIONS IN AGRICULTURE (MOIRA 1)

MOIRA 1 is at once the most limited of the global models examined and the one that opens the greatest range of possibilities for further development along the disciplinary lines of environmental biology. The model was constructed to examine the potential of the globe to provide food for a doubling population. The modelers viewed hunger as a product of maldistribution of income between nations and within nations above and beyond the problems of physical limitations on production. Accordingly they disaggregated the model into 106 nations and 12 income classes. This permitted detailed examination both of physical capability to produce (model production functions were derived from soil maps and climatological data) and of the trade patterns that establish patterns of consumption. As shown in Figure 6, however, it also pulled the model's focus away

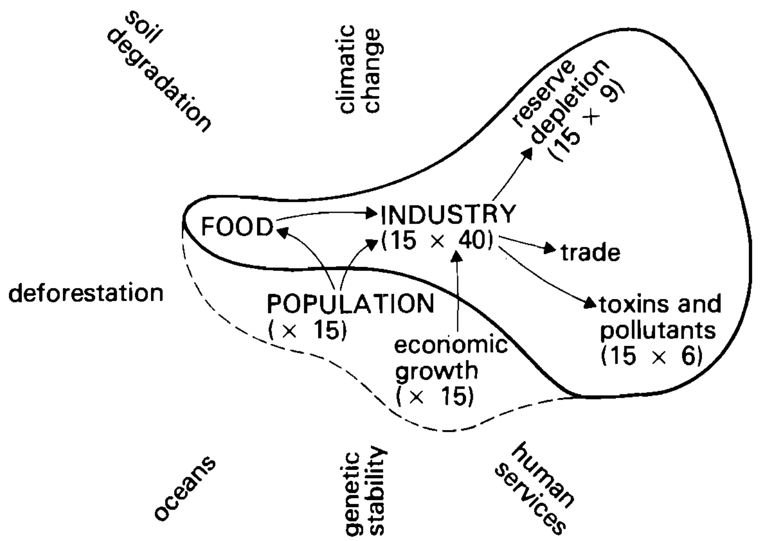


FIGURE 5 Environmental aspects covered in the UN World Model (———, endogenous; – – – –, exogenous).

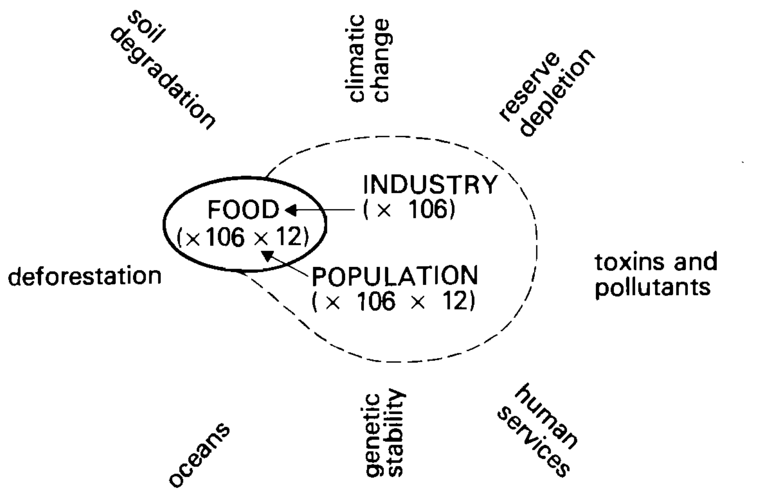


FIGURE 6 Environmental aspects covered in MOIRA 1 (———, endogenous; – – – –, exogenous).

from environment. Soil degradation, climatic change, fuel scarcity, and deforestation, all of which may greatly affect agricultural production in some nations, were not considered in MOIRA 1.

Because the model is based on soil maps and climatological data and because it is highly disaggregated it offers scope for detailed collective treatment of many serious environmental problems including salination, erosion, desertification, organic-matter depletion, and deforestation. The MOIRA group have already begun manipulating their data base to examine the effect of these problems on yields, as described in the paper by Faber and van Asseldonk (this volume, pp. 121–132). Given further support they could probably rework their data to map the agricultural implications of climatic change, the contribution of soil organic-matter decomposition to atmospheric CO_2, the potential for fiber production through intensive forestry, and many other important factors which environmentalists can at present only guess at with low levels of precision.

7 GENERAL OBSERVATIONS

In compiling the observations on the five models we are led to general observations on the treatment of environment in global models. Here we discuss first the general state of the art and second the extent to which various aspects of the environment have and have not been considered in global models and the ways that global modeling might profitably be expanded to cover important aspects of environment that heretofore have been largely ignored.

7.1 State of the Art

7.1.1 Consensus of Findings

A comparison of the conclusions of the various global models leads to one clear statement: "Watch agriculture". Even assuming no negative environmental effects on production, regional agricultural systems will in the next few decades be pushed as they have never been pushed before, and hunger is likely to increase. This implies that aspects of environment that affect agricultural production will have critical import for human and ecological welfare in the next decades. If the food situation is becoming tighter, the possible destructive impacts of climatic change, soil degradation, and genetic instability are becoming greater. Simultaneously, pressure on agriculture is likely to be transmitted to forests, grasslands, and other ecosystems. The poor and hungry often have no choice but to clear forests and to put more animals to pasture. Thus the quest for survival may compel them to the destruction of agricultural watersheds and the overgrazing of pastures. The connection between resource availability (e.g. fuel costs) and agricultural production also appears to be important. These observations suggest that the complex of factors affecting fertility and mortality – and thus the number of people that will need food one or two generations hence – is also critically important for time horizons of more than one generation.

7.1.2 Methodology and Scope

A methodological comparison shows that many approaches have been used. All have revealed something but all remain crude first approximations. A general trend toward increasing disaggregation, decreased scope of environmental coverage, and reduced endogenization of environmental factors can be observed. No later model has equaled World 2 or World 3 for comprehensiveness of environmental scope or extent of system closure.

One strong factor in the retreat of environmental scope seems to be fear of criticism. Meadows and Forrester were severely attacked for sensationalism because of their treatment of environment, and later global modelers seem to have avoided being branded prophets of doom by de-emphasizing environment. If MOIRA 2 can achieve a scientifically credible disaggregated treatment of soil degradation this will constitute a significant reversal of the trend away from environment in global modeling.

7.2 Environmental Aspects: Distribution of Attention

A look at the way attention has been distributed by global models across different aspects of the environment (see Figure 7) shows that some of the most critical areas have largely been ignored while areas of lesser importance have been emphasized. Deforestation is the most prominent omission, and a needless one. No one has exact parameters on a global basis on forests, their rates of disappearance, and their role in protecting watersheds, holding soil, fixing CO_2, and providing firewood; however, direction and order-of-magnitude estimates can be made. Likewise the connections between poverty and forest clearing and between fuel costs and firewood gathering are not easily reduced to simple mechanisms and estimable parameters. However, once again, enough is known to make

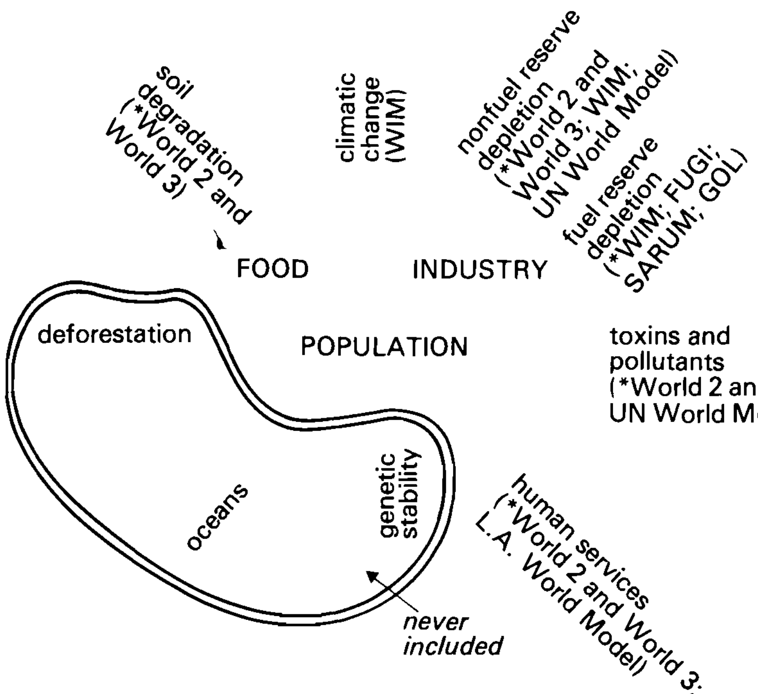


FIGURE 7 Environmental coverage of global modeling to date (an asterisk (*) indicates a model in which the particular aspect is endogenous).

plausible guesses, and the process of making alternative guesses and observing the model's sensitivity to the parameters and mechanisms assumed would be valuable; it would lead to a better sense of what data are needed and of the costs that may be incurred by the poverty of our present knowledge of the global forestry situation, and, above all, it would prevent the dangerous assumption that the health of the biosphere is unaffected by wide-scale forest removals.

It is also significant that no global model has yet dealt explicitly with genetic stability, oceans, or highly toxic materials, that only the WIM has attempted to deal with climatic change at all (and the WIM included only a simple index of CO_2 release through fuel combustion), and that the only treatment of soil degradation to date has been the simplistic globally aggregated treatment in World 3. In sum, natural biological and climatological systems are underdeveloped areas in global models.

By comparison, variables that are easily related to industrial activities – especially pollutant generation, reserve depletion and human services – have been given relatively comprehensive treatment; this observation would become stronger if more global models had been included. The pressure to include fuel-resource dynamics in global models has become very strong in the last few years and most recent models have given it great attention. For example, GOL*, SARUM, and FUGI are all energy conscious and the Berlin (Wissenschaftzentrum) model is almost certain to look at petroleum-related conflicts. SARUM also includes detailed treatment of pollution generation.

On balance it appears that global modeling has expanded extensively into rich people's environmental problems (pollution and depletion of mineral resources) while retreating from environmental problems such as deforestation and soil degradation which bear directly on the basic needs of the world's poor. Likewise it has expanded into questions of global economic welfare while retreating from the question of biological and climatological health and stability.

In my opinion, in both scientific and humanitarian terms, the trend is a misallocation of resources. Scientifically the most interesting thing about early global models was their attempt to see the world's biotic and economic systems as an interacting whole. It is disappointing to see the biota dropped from the picture. In humanitarian terms a blind eye is turned on a billion and more people whose subsistence depends on the sustained productivity of their fields, the reliability and cleanliness of their water supplies, and the availability of firewood and other biologically derived fuels. There is also a failure to look at the question of how the poor man's most available resource – human labor – can be mobilized in the labor-intensive task of rebuilding damaged ecosystems and sustaining those that are now threatened.

There are some signs that the trend is turning. MOIRA 2 shows promise of providing the basis of a scientifically sound and comprehensive treatment of the dynamics of global agricultural soils. MOIRA 2 could be extended to cover forestlands as well. Attention is mounting on the CO_2 question, and research in that direction will require better accounting on a global basis for changes in the carbon content of soil and forest ecosystems. Given resolve and persistence in the next five or ten years global modeling could develop a credible scientific base for understanding the long-term interrelationships between human activities and the natural systems of our planet.

---

* GOL = the grains, oils, and livestock model of the US Department of Agriculture.

REFERENCE

Barney, G.O. (Editor) (1979). Entering the 21st Century: Report of the Global 2000 Study to the President. US Government Printing Office, Washington, D.C.

DISCUSSION

Steger *drew attention to the fact that many toxic substances in widespread use today may have extremely severe ecological impact if used over 25 or 50 years. Although their impact is not felt today it would be of the utmost necessity to include their effects in a global model reaching that far into the future.*

In reply Robinson *agreed that toxic substances definitely require proper attention; still, it is even more important to reflect in the models issues of more immediate concern (like deforestation).*

Driessen *added that these problems are not independent: deforestation leads to a quicker accumulation of toxic salts in the topsoil, precluding the growing of crops, at an estimated rate of a hectare per minute. In the humid tropics the fertility of the soil is often lost owing to the fact that deforestation leads to erosion of the topsoil and the subsoil has a high level of aluminum which is toxic to crops.*

Robinson *said that it is a question of classification whether this problem should be regarded under the heading of "toxicity" or under "erosion".* Parker *opined that it should not prove too difficult to treat deforestation in a world model; in SARUM it could be done.* Robinson *added that "deforestation" is often regarded as "land development for agricultural use"; it depends crucially on the circumstances whether the positive or the negative side is justified.*

Steger *stressed the necessity to disaggregate geographically any treatment of environmental parameters; often the variations are just as important as the averages.* Robinson *agreed fully; if one already knows that the renewability of a forest may vary from square mile to square mile then it is obviously even more important to consider such variability when one proceeds to larger areas.*

Mesarovic *suggested that one should differentiate between two types of problems, both of which deserve thorough research: one is the area of human impact on the environment and the other is the ecological interrelationships themselves.*

Parker *expressed a word of warning concerning the expectations from a global model. It would be more than fallacious to judge a model according to whether it could answer any kind of detailed question, from local deforestation to the eutrophication of a particular lake.* Bruckmann *replied that the historical development was the other way around: global models reflected environment too little, and it was generally felt to be desirable that global models should go more deeply into environmental questions than they had done in the past.* Parker *clarified that global models should certainly contain environmental considerations but, being "models", they should not overburden themselves with details. For detailed studies special (not global) models should be used. In a global model it might suffice to treat environment exogenously, in the form of alternative scenarios.*

Mesarovic *disagreed: it would be misleading to have, for example, a very detailed price-related trade economic model and a very detailed population model while ignoring issues like CO_2 in the atmosphere.* Bruckmann *seconded this view: in the case of both the Latin American model (Bariloche) and MOIRA, environment was practically excluded; the exogenous environmental considerations made were generally overlooked by the readers.*

Roberts *asked* Robinson *how she thought that all these individual aspects of environment could be incorporated into a global model. In reply* Robinson *reported an exercise done by the Global 2000 team, namely to cut existing linkages within well-known models (World 3, Mesarovic–Pestel, Leontief); without these linkages the models represented more or less official projections made independently from each other, while with the linkages the models showed considerably worse performance in terms of human needs. From this exercise it could be concluded that any additional linkage included (e.g. between deforestation and agricultural development) would yield a much more pessimistic outlook than those which all models without such linkages provide.* Mesarovic *gave an example underlining this view: the amount of coal that many models assumed to be used by 2030 might increase atmospheric CO_2 by 69–100%, which would have strong repercussions even on the energy options themselves. If this linkage were included in a model now it might influence energy policy at a much earlier date.*

Kellogg *added that the knowledge accumulated by the ecologists is far from satisfactory, for example, in deforestation.* Robinson *disagreed: data available on ongoing developments, often alarming, in many parts of the world allow a fair estimate of the order of magnitude of the parameters involved, sufficient to be incorporated in modeling work.*

Food and Agriculture

LOCAL PROBLEMS IN A GLOBAL SYSTEM: THE APPROACH OF IIASA'S FOOD AND AGRICULTURE PROGRAM

Ferenc Rabar
Food and Agriculture Program, International Institute for Applied Systems Analysis, Laxenburg (Austria)

1 THE PROBLEM – AN UNSATISFACTORY DEFINITION

The Food and Agriculture Program of the International Institute for Applied Systems Analysis (IIASA) began its research with the ideals of (1) evaluating the nature and dimensions of the world food situation, (2) identifying the factors affecting it, and (3) finding alternative policy actions at the national, regional, and global levels, in order to alleviate existing and emerging food problems.

This cautiously general and sufficiently vague statement at the beginning of the research did not even define what we meant by food problems, thus giving us ample opportunity for investigating the field and enough freedom to specify our subject (Rabar, 1976; de Haen, 1978; Schmidt, 1977; Neunteufel, 1977; Popov, 1978). After the crisis of 1973–1974 and the World Food Conference it was clear that the present existence and the future threat of hunger in a large number of countries is a world problem. However, to formulate this world problem in the form of well-specified research additional investigation was needed, the more so because hunger is a local phenomenon and its causes are country specific and subject to the following factors: (1) historical (development stage, inefficient traditional production methods, insufficient diets); (2) physical (resource scarcity); (3) economic (income distribution, lack of capital); (4) social and demographic (farm size, tenure system, population explosion, etc.).

Global hunger, used as a collective term for the sum of local "hungers", is meaningless as a research subject unless we specify how the local problems arise in the different countries.

However, the fact that hunger problems are local does not mean that they are independent. It is almost commonplace to say that we are living in an increasingly interdependent world. Hunger exists in this interdependent world.

Although it is not the result of interdependence it may be heavily influenced by different interactive mechanisms between countries. It is quite justifiable to ask whether a given interaction mechanism alleviates or aggravates an existing local hunger problem. Conversely, there can be no local solution of the hunger problem which does not have an impact on the prevailing mechanisms oi interaction between countries.

Thus in addition to specifying the local structures within which the problems arise it is also necessary to specify the interaction of these structures in order to arrive at a satisfactory definition of the research problem. The specification of the local structures and their interaction is nothing other than the definition of the system in which the hunger problems arise. The definition of the system and the implications of the definition will help us to obtain a more satisfactory definition of the problem.

2 THE SYSTEM

2.1 Global System versus Global Figures

In trying to evaluate the global food situation it is a common procedure to add up national figures and to discuss regional or global resources, population, nutritional requirements, etc. This approach is invaluable and sometimes indispensable, yet in certain cases it has led to a crude error: mistaking the clock-face for the clockwork. However trivial this error may appear to be, a great many global modelers have committed the sin of adding up similar elements of different national systems across the borders and treating them afterwards as realities instead of as useful abstractions. Once created, the global aggregates began to live their own self-contained lives; instead of indicating the outcome of sophisticated functions they began to function within themselves. For example, to extend the behavioral rules of Brazilian farmers to Latin American farmers is a bad mistake because one is dealing not only with a different level of aggregation but also with an entirely different system.

Of course it is perfectly justifiable to speak about global food needs, the world's carrying capacity, and the globe's resources for food production. In fact a very large number of books have been written about the present and prospective global food situation. Detailed studies have been written on the estimated number of people that can be fed by the globe's resources; these estimates range from 8 billion to 150 billion people (University of California (1974), 8 billion; Klatzmann (1975), 10–12 billion; Revelle (1974), 38–48 billion; Clark (1967), 45 billion; the Model Of International Relations in Agriculture (MOIRA) (purely technical capacity), 90 billion; Clark (different assumptions), 150 billion). These global studies can be extremely useful either as rough long-run estimates or as a framework for some partial investigations. They can show us the quantity of reserves that are hidden in the present food production system but since (except for MOIRA) they do not describe how the system really functions they cannot suggest actual policy measures for its better use. To suggest policies we need a different system definition. Instead of identifying the global food system with a set of aggregated global figures we have to identify it with the mechanism generating those local figures of which the global aggregates consist. In other words we need a functional definition. Accordingly we define the global system of food and agriculture as a set of national agricultural systems which are embedded in national economies interacting with each other. The mechanism of this interaction can be explored, modeled, and altered by national and international policies. This definition implies that (1) the global development is the result of interactions between countries and (2) national development is heavily influenced by these interactions.

Furthermore, in constructing our functional definition of the global food system, the following important points must be borne in mind:

(1) We do not have global technological decisions. What we have is a set of technological decisions in the individual countries, which are influenced by each other and induced by their individual economic environments.

(2) We do not have global resources used in the interest of humanity. What we have are national resources used to the full advantage of those countries which possess them, and not really in the interests of *all* countries.

(3) We do not have global decision makers. What we have is a set of national decision makers. They act in a specific environment, pursue specific goals, and use specific instruments. However, they do not act completely independently. Their actions have indirect effects on other national systems by provoking reactions, retaliations, defensive measures, or cooperative gestures.

However perfect a conception can be developed theoretically for a global order, we have to recognize that in the real world "order" is always an inconsistent set of compromises between different nations. The nations are not like an army marching towards a common goal. They are more like a set of players unwillingly accepting (or sometimes refusing) the fuzzy rules of a changing game.

This vision of the world strongly implies that a definite structure of the system in which the problems appear is needed.

2.2 The Key Role of Countries

In this structure the countries have a crucial role. For our present analysis, countries should ideally be units where (1) resources are available, (2) technologies are available, (3) production, consumption, and prices are mutually determined, (4) decision makers can be identified, (5) policies can be discerned, and (6) overall economic decisions induce agricultural changes.

Agricultural systems are integral parts of the countries' economic systems and cannot be understood when studied apart from this environment. They function under the umbrella of national economies and they are cushioned by government policies against outside shocks (e.g. "30 per cent of the average farm income in EC-6 [the six-member EEC] is derived from public subsidies" (Jansen, 1975)). The enormous role of national economies and government policies is even more effective when the economic system is more vigorous. Statements like "The developing rice-exporting countries are not competing with US rice producers but with the US Treasury" (Abel, 1975) or "A decision made in Brussels or London or Washington can, overnight, destroy a potential export market (of a developing country)" (Johnson, 1975) are completely justified within this context.

We can summarize the implications of our definition as follows.

(1) Resources, needs, stocks, etc. cannot be first added up to a global level and then *afterwards* viewed as directly interacting system elements. We can speak about "South American resources" or "Africa's food need" but we cannot meaningfully use these quantities in direct functional relationships. The interaction of the food system's elements takes place on the national level and these elements come into contact with system

elements of other countries only indirectly, and in ways that are heavily influenced by government policies. Thus in global model building countries have a key role as the main building blocks.

(2) The country systems interact in a complex way. Whatever happens in a given country has an indirect intricate effect on the global system and, whatever changes in the global system, the changed environment induces new adjustments in the individual countries. Local and global changes are inseparable and they mutually condition each other.

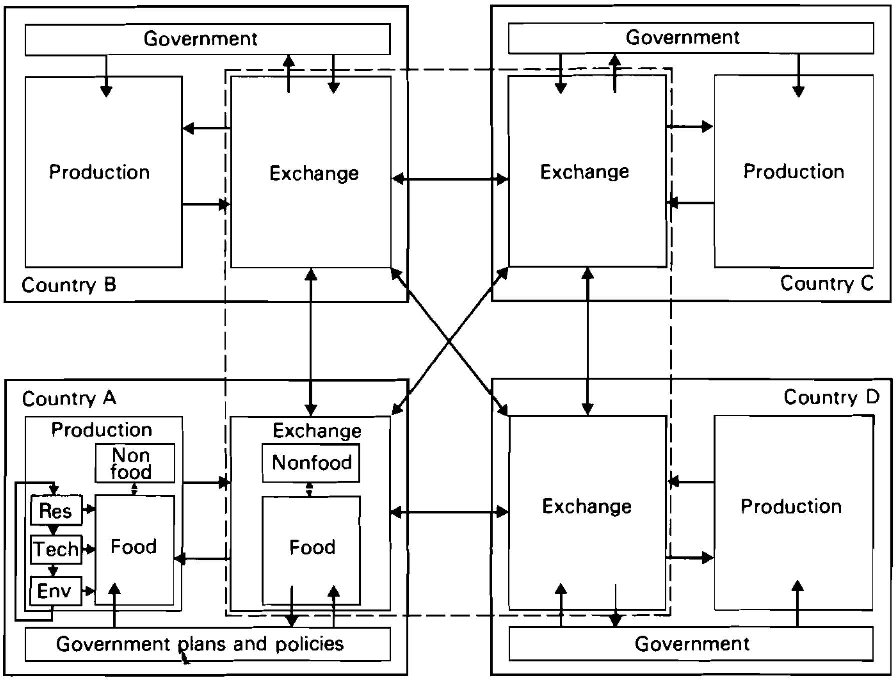


FIGURE 1 The interactions within and between countries implied by the definition of the food and agriculture system.

Figure 1 illustrates in a sketchy way the approach that follows from these implications. The first interactions between resources, environment, and production take place at the national level where they are embedded in the national economy and are influenced by the nation-specific government policies. The resulting lagged supply enters into the exchange module which is linked with other countries and is solved simultaneously with their exchange modules. Thereby domestic and international markets, although separated by government policies, represent a single consistent system. It is through exchange that nations interact. However, learning from past experience in the field of exchange, governments and producers adjust their targets and policies. As well as short-run adjustment a long-run process is also being brought into motion: the slow adjustment of technologies and their impacts on the environment and on natural resources.

Food problems, being highly complex, force us to use a systems approach. Realizing that they are decentralized we focus on the *national* food and agricultural *systems*. However, taking into account their interdependence we try to link the national models through a special methodology.

2.3 The Need for Simplification

To build a global system from national models requires an immense, almost impossible, amount of work. Realistic models of about 150 countries require such vast organizational and scientific work that it is beyond our capacity and time limits. We therefore had to turn to a simplification that does not contradict our basic principle that the nations' structures and policies should be identifiable in the system.

Although it is theoretically true that the global development is the result of the interactions of *all* countries, the possible impact of various countries can vary considerably. From a practical point of view the system can be simplified without changing the interactive mechanism by reducing it to a limited number of those countries which exert a relatively large effect on it. The system will still be closed, as the "rest of the world" appears within it, but only the interaction of "the most important countries" will be described in a detailed way.

To find out which are "the most important countries" in the food scene – a vague and tentative definition – we introduced a very abstract and very academic method. We asked the question: What is the minimum number of countries that can be chosen that includes at least 80% of the world's population, production, arable land, agricultural imports, agricultural exports, and hunger? We used an integer programming method and although some countries were added and some dropped for qualitative and practical reasons we ended up with 20 "countries" (only two of which are country groups: the European Economic Community (EEC) and the Council for Mutual Economic Assistance (CMEA)) that are very close to the starting requirements. Since the remaining 20% is shared by about 120 countries (each having on average a 0.17% impact on the world totals discussed, and not acting as a coalition) we can safely say that these 120 countries are exposed to the effects of everything happening within the selected 20 countries without being able to influence the international food market.

Thus we have arrived at the core of a system which is limited and simplified but which can be extended, without changing its basic structure, in two ways, as can be seen from Figure 2.

One important way to extend the system is to replace the simple national structures by detailed national models including a broader product list, describing production, exchange, and government policies in a sophisticated and realistic way, using more reliable national data, etc. – in other words to increase reliability, credibility, and realism on the national level.

Another way is that any new countries to be investigated additionally can be "taken out" from the rest of the world and added to the ones that are individually handled. Thus the original country selection can be modified and regrouped according to the specific purposes of investigation. However, the first way of extending the system does not change the national structure. Similarly, the international structure will not be greatly modified by the second extension possibility.

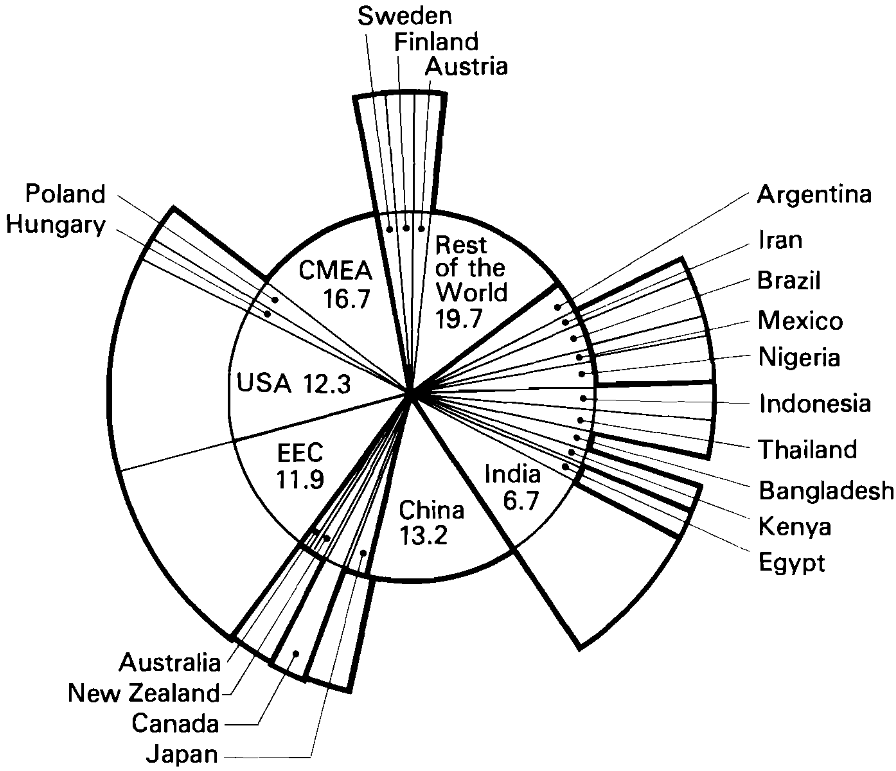


FIGURE 2 The core of the system showing the 20 selected countries and how the system can be extended in two ways.

How large an area is covered by the original selection of 20 countries can be seen from the map of the world in Figure 3. Developed and developing nations are shown separately. It is interesting to note that, instead of a North–South problem, a clearer picture emerges of a tropical-zone versus temperate-zone agricultural problem.

2.4 A First Approach to the Selected Countries

What can be said about the selected countries at the outset? Table 1 already shows an imperfect tentative classification; it clearly separates developed and developing countries. The developed countries have a dominant share in the international market. 53% of the world's population participates in only 8% of the world's agricultural imports. It is precisely those who do not *produce* enough food who cannot *import* it either.

Table 1 makes another classification as well. Based on studies by the IFPRI and the World Bank it separates those developing countries with no serious balance-of-trade problems from those that struggle with foreign-exchange problems. The first idea was to distinguish, within the second group, between food exporters and importers. The exporters have to follow the dominant demand structure of the developed countries while the

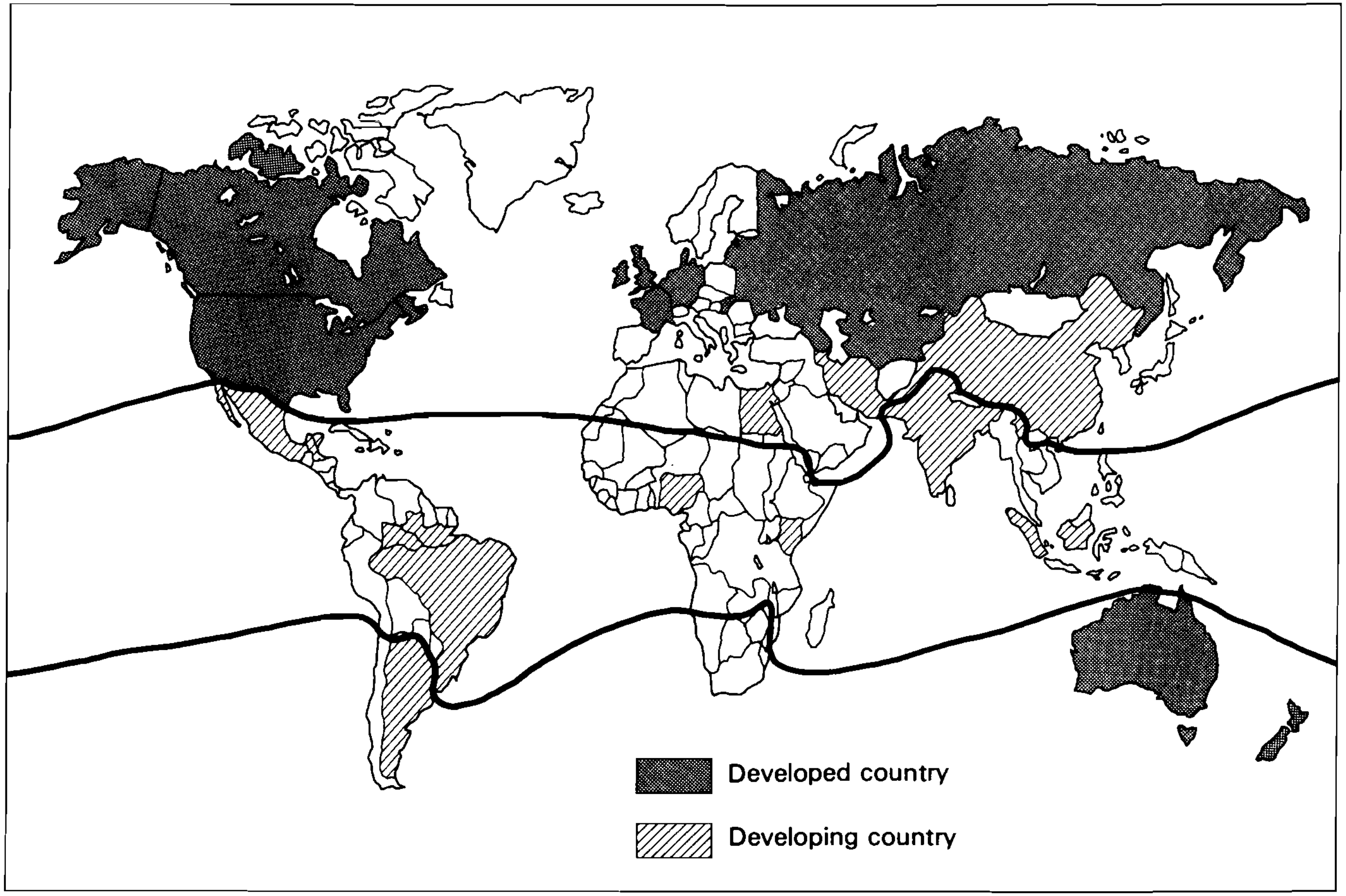


FIGURE 3 The area covered by the 20 selected countries.

TABLE 1 Percentage shares of world totals of the 20 selected countries in the system (1976).

Country	Population	Production	Land	Imports	Exports
USA	5.3	12.3	9.8	8.07	18.85
Australia	0.3	1.6	1.3	0.25	5.00
New Zealand	0.1	0.5	0.1	0.14	2.09
Canada	0.6	1.2	2.0	1.99	3.25
EEC	6.4	11.9	3.3	38.83	26.05
Japan	2.8	1.8	0.4	8.36	0.05
CMEA	9.0	16.7	17.5	12.72	5.74
Subtotal	24.5	46.0	34.4	70.36	61.03
Pakistan	1.8	0.9	1.4	0.34	0.34
China	21.4	13.2	17.3	1.64	1.81
Nigeria	1.6	0.5	1.6	0.50	0.40
Argentina	0.6	2.0	1.7	0.14	2.86
Indonesia	3.4	1.6	1.5	0.64	1.02
Iran	0.8	0.5	0.8	1.23	0.13
Mexico	1.5	1.5	1.3	0.35	0.82
Thailand	1.0	1.1	1.1	0.18	1.23
Brazil	2.8	4.7	4.0	0.75	5.55
Bangladesh	1.9	0.7	1.1	0.34	0.11
Egypt	1.0	0.7	0.3	0.94	0.56
India	15.5	6.7	14.6	1.06	1.30
Kenya	0.3	0.2	0.2	0.06	0.33
Subtotal	53.6	34.3	46.9	8.17	16.46
Total	78.1	80.3	81.3	78.53	77.49

importers are exposed to the market changes and can respond only by reducing their import quantities; however, it was soon discovered that there have been rapid recent shifts in the countries' positions (e.g. Mexico is turning out to be a net importer) and that being a net importer or exporter is not very meaningful if applied to those countries that have hunger and are in a marginal situation in the international market. For instance, India's position as a net food exporter does not mean food surpluses, and neither does it show how far biological needs are met in the country. Again, it would be premature to say that the developed countries' market is almost closed and disconnected from the developing nations and that the links between the two are so weak that they can be neglected in the investigations. It can be shown that although quantitatively there is no heavy interdependence between them the nature of their interdependence is such that it can be detrimental to the weak.

It can be seen from Figure 4 that if a powerful economy is connected with a weak one then (1) the different proportional weights of the trade linkages (in the rich country a specific trade relation plays only a minor role), (2) the nature of the exchanged goods (staple food, capital goods, and raw materials imported by the developing country and mainly luxury goods imported by the developed country), (3) the substitution possibilities within the advanced technology of the developed country (e.g. synthetic fiber for jute

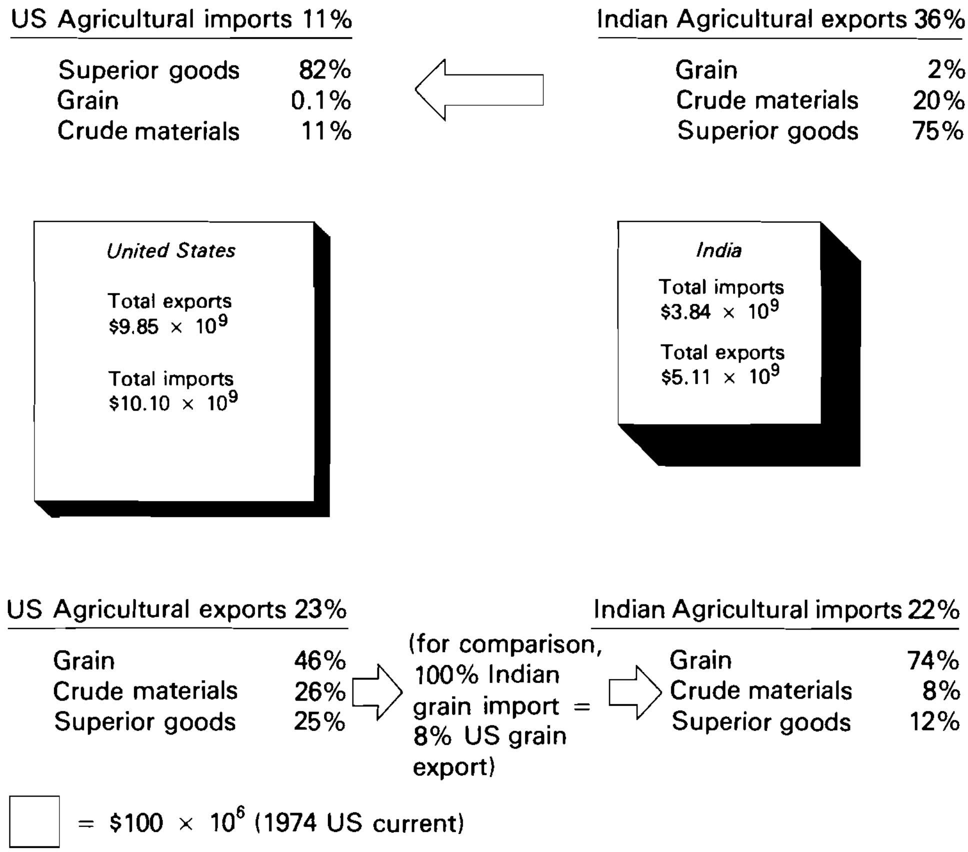


FIGURE 4 The interdependence between a powerful economy (the United States) and a weak economy (India) (from FAO, 1976).

and cotton, synthetic materials for rubber), and (4) the highly effective government protection backed up by a large budget in the developed country all make a considerable difference in their positions, creating an interdependence which is harmful for the weak. The problem is then to find a way to solve this undesirable interdependence.

We may look at the system in another way. Josling (1975) has classified the countries according to their per capita kilocalorie consumption and production and we have prepared a map of the selected countries on this basis, also introducing some dynamics from 1961 to 1975 (see Figure 5). Because of the differences in scale it seemed valuable to enlarge a part of Figure 5 as shown in Figure 6.

According to Figure 6, the countries can be grouped into (1) those which move toward a clear exporter position, (2) those which increasingly import, (3) those which try to be self-sufficient or try to move upwards parallel to the self-sufficiency line, and (4) those which are trapped.

As illustrations of a country that is increasingly importing and one that is trapped we show the developments of Japan and India from 1961 to 1975 in Figures 7 and 8, respectively.

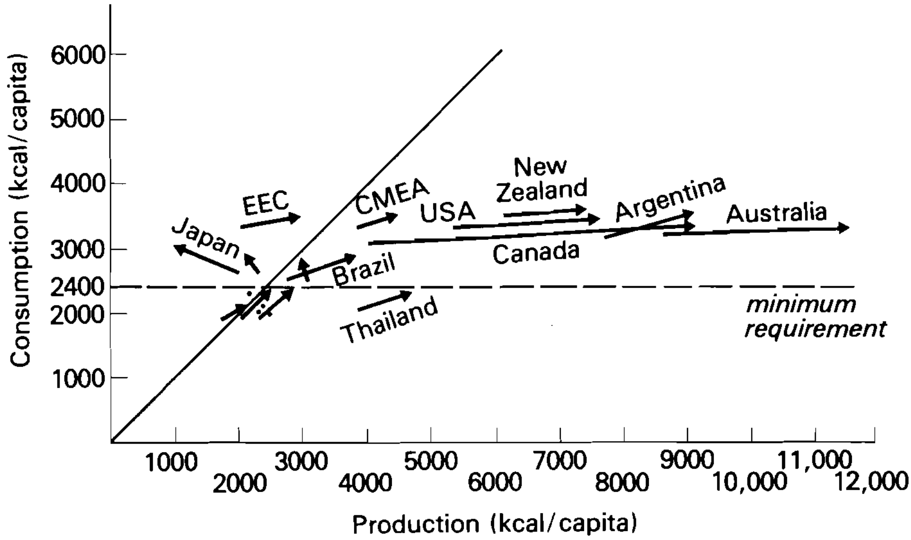


FIGURE 5 Per capita kilocalorie consumption versus per capita kilocalorie production for the 20 selected countries showing the shifts between 1961 and 1975.

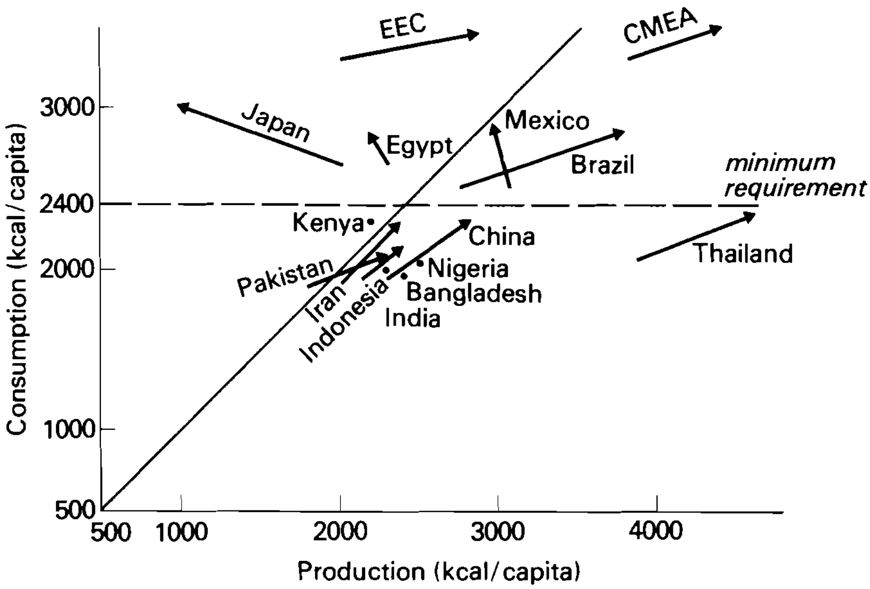


FIGURE 6 An enlargement of part of Figure 5.

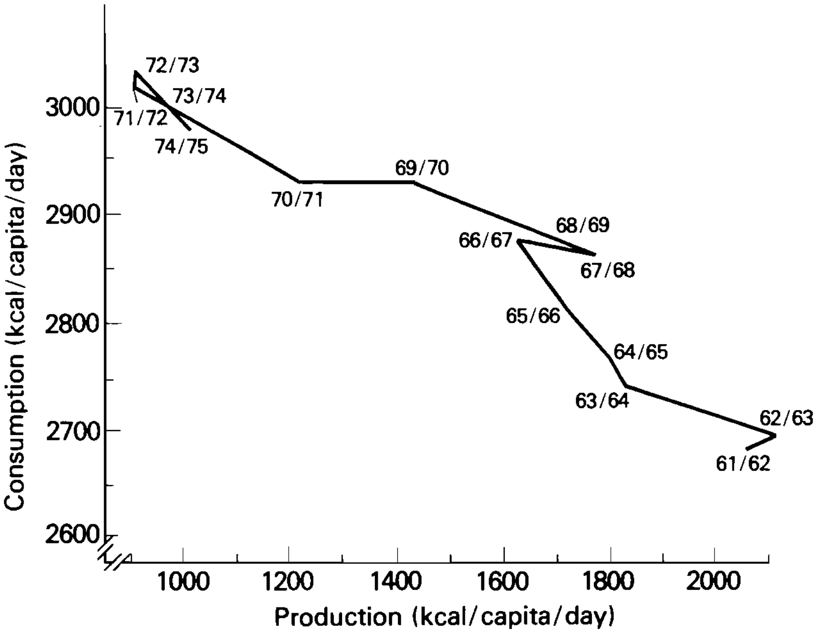


FIGURE 7 Per capita food consumption versus per capita food production for Japan, 1961–1975.

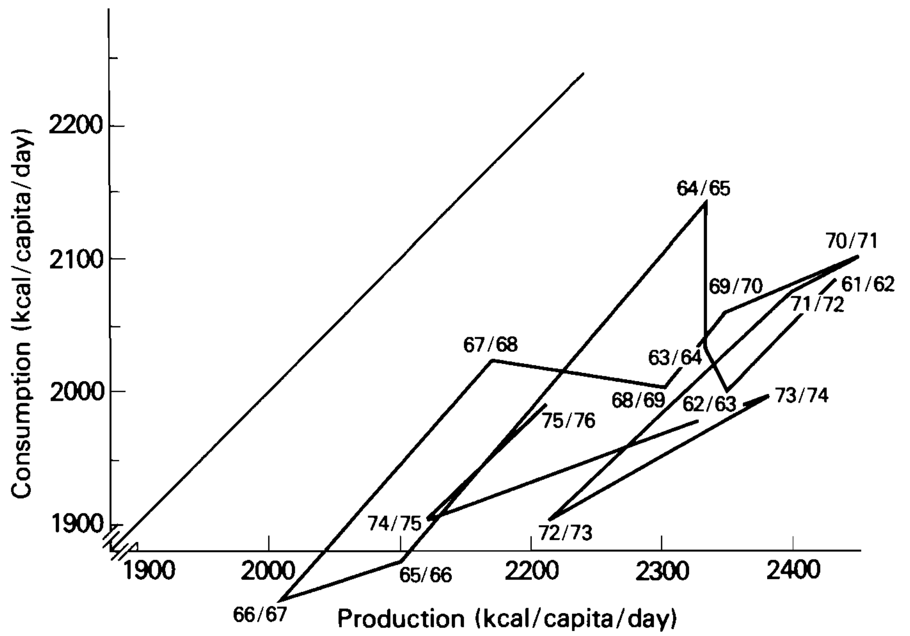


FIGURE 8 Per capita food consumption versus per capita food production for India, 1961–1975.

Some tentative statements can be made based on Figures 5–8. (1) There are only a few countries moving towards a clear importer position. (2) Poor developing countries cannot afford imports. Even some of the oil producers try to move along the self-sufficiency line. (3) Fast population growth leads countries into "traps", and they are vulnerable to the effects of adverse weather changes to a degree largely forgotten in present-day developed countries. They have no policy choices: they must utilise *everything* in order to eat, no matter what the consequences are for the environment, equity, resource depletion, unemployment, etc. However trivial these statements might sound they bring us nearer to a better problem definition.

We have seen the relative position of the selected countries in the food field. We have mentioned that the interdependence between developed and developing countries can lead to disadvantages for the poorer countries but we have not yet dealt with government policies and their role in bringing the countries to their present positions. The food market is perhaps the most distorted market in the world. Both national and international supplies and demands are influenced by government policies (Swanson, 1975; Schmidt and Carter, 1978).

These government policies are so sophisticated and complex, and in some cases mutually contradictory, that their outcome is often unpredictable, even in the countries where they were conceived and applied. Even more unpredictable is their secondary effect on the international market and on other countries. As it is impossible to give an overview of the whole policy field, we will restrict ourselves here to one example: the policies of the United States, as summarized in the simplest possible way in Figure 9. Although this is an oversimplified tentative representation of a much more complex field, it gives an idea of the difficult consistency problems that can arise when a set of policy instruments is applied in a combined way.

As we said initially, government policies are certainly not the main causes of hunger in the developing areas. Yet, because small changes in the large countries can generate large changes in the small countries we can rightly suspect that policy changes can, sometimes, make quite a difference in some countries (Littlechild et al., 1979).

3 THE PROBLEM REVISITED

After the first tentative description of the system where the problems arise the first classification of some better-defined problems can be made. However, it should be clear that during the progress of research further modifications and refinements can be expected in the problem definitions.

We separate short-run and long-run problems. Within both classes the problems mostly concerned with the interaction mechanisms will be distinguished from those concentrating on local problems.

3.1 Short-Run Problems

3.1.1 In the Interacting System

(1) It has been shown that some countries are trapped; i.e. they do not meet the minimum nutritional requirements and they cannot improve their situation because the

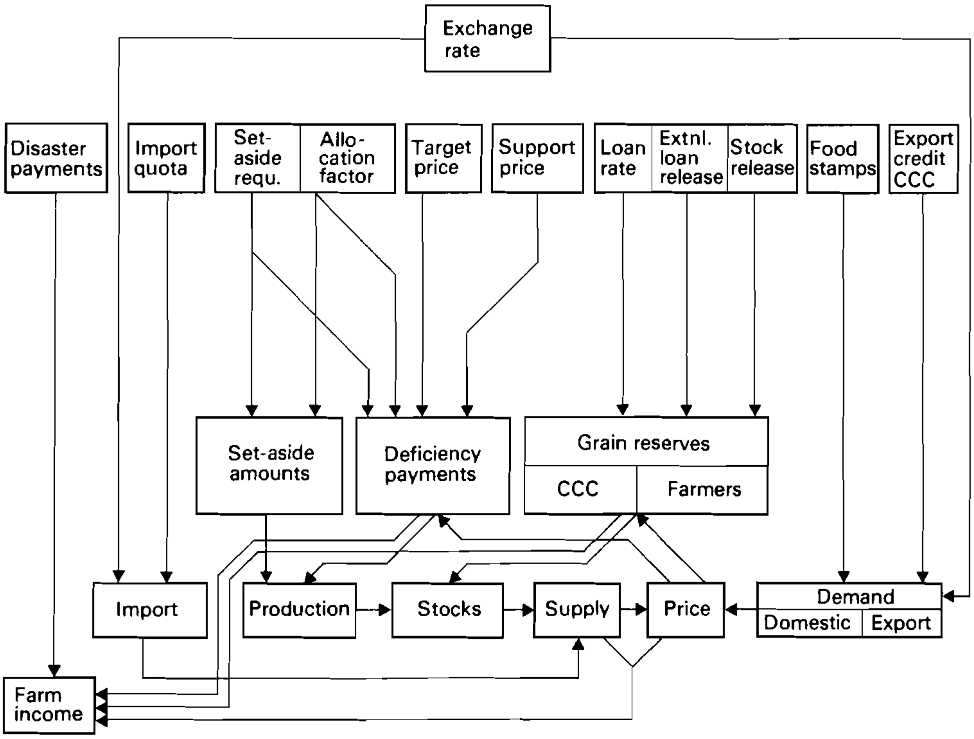


FIGURE 9 The system of US agricultural policies.

increase in food production can hardly keep pace with population growth. They cannot produce enough and cannot import enough. This leads to the questions: In which countries can similar difficulties be expected in the next 15 years? For how long will they last, and how serious will the shortages be?

(2) It has been shown that the shifts of the different countries towards exporter or importer positions can be in the long run inconsistent. What kind of future tensions can be expected from present market developments?

(3) What are the ways of avoiding undesirable types of interdependence? (a) What are the chances of selected developing countries reaching a takeoff position if no changes are expected in the government policies of the developed countries? What are their best strategies for reaching the takeoff position? (b) What can be expected from a general or partial market liberalization for the developing countries? Many studies contend that while "there would be clear gains for North American farmers and for consumers in Europe, there would be no reduction in the world hunger" (Christensen, referring to MOIRA). Even if advantages are assumed, a "too sudden liberalization may disrupt domestic production and employment and set industrialization back" (World Bank). Thus the problem is not unambiguous. (c) What would happen if, instead of the present "randomly" distorted market, we introduced a market deliberately distorted in the interests of the developing countries? All the various policy proposals belonging to this field (e.g. the New International Economic Order, the United Nations Conference on

Trade and Development (UNCTAD) Integrated Commodity Program, the Lomé Convention, and other commodity agreements) should be simulated to calculate their consequences for all parts of the system. Price stabilization and buffer-stock policies also belong in this "regulated-market" conception. (d) Would self-sufficiency be possible in some individual developing countries or at the level of country groups? Which would be the natural partners with complementary economies? How far can the developing countries' market be disconnected from that of the rest of the world?

3.1.2 Local Problems

(1) What are the best strategies for selected developing countries for reconciling consumer-oriented price policies and production incentives? (Fair-price shops? Procurement prices?) In some countries (e.g. Egypt) procurement prices are set to promote state-controlled export activities. Here again, the problem of production incentives versus balance-of-payments improvement should be solved.

(2) What kind of corrective domestic income-distribution measures can be taken to avoid hunger if neither production increases nor imports are possible?

(3) In a given environment, what kind of government policies can be used to improve national diets?

(4) What are the feasible alternative production structures for given countries? In particular, export-oriented and nutrition-oriented structures should be compared.

3.2 Long-Run Problems

3.2.1 In the Interacting System

(1) Where can extraordinary pressures on domestic production be expected and where do such pressures already exist? What kind of technologies are likely to be launched by these pressures? What kind of feedback effects can be expected among resources, technologies, and environment in these countries?

(2) Which technologies are feasible only in a protected environment and in which direction would they change if protectionism stopped?

3.2.2 Local Problems

(1) The investigation of the energy-intensiveness of production in the "pressure" countries and its prospective development with further-increasing energy prices is important. Which technological options will be foreclosed by technologies being quickly introduced without proper adaptation time?

(2) What are the long-run consequences of labor-saving technologies in countries where urban unemployment presently exists or may exist in the future?

(3) What would be the consequences of opening up hitherto closed ecological systems?

(4) What would be the effects of long-run soil deterioration and soil loss as a result of undue exploitation of natural resources under short-run production pressures?

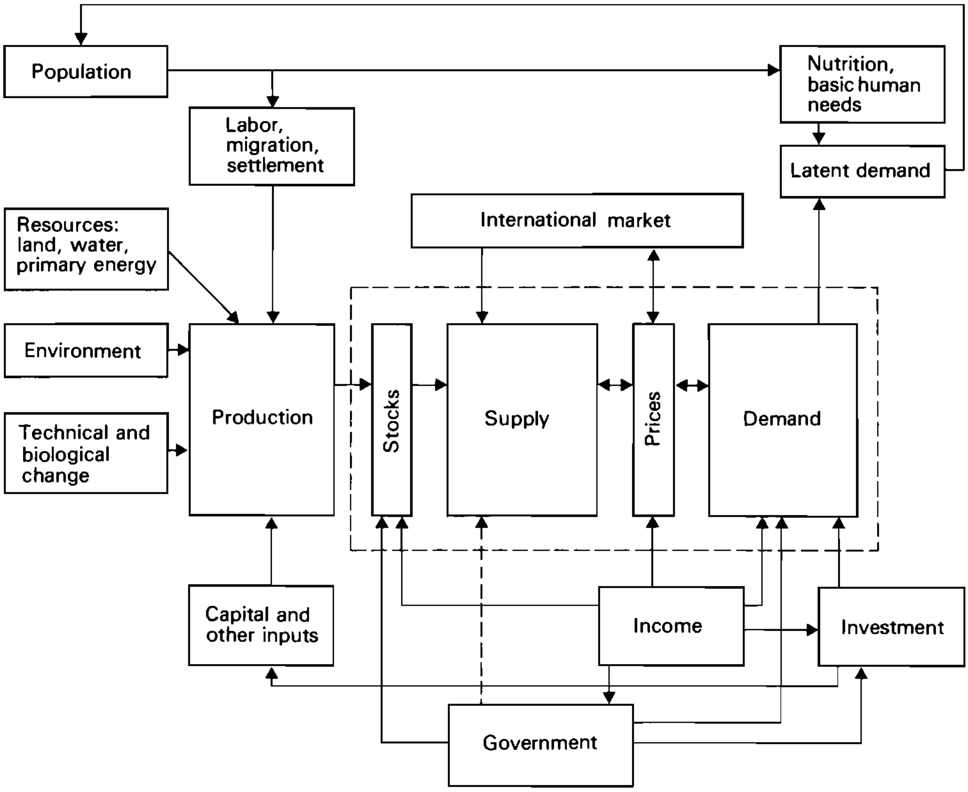


FIGURE 10 The reference system developed for the country models.

4 THE APPROACH

In the field with which we are dealing short-run and long-run problems are interrelated. It is impossible either to distinguish perfectly between them or to separate them in a satisfactory manner. Yet, when looking at the reference system in Figure 10 that we have developed for the country models we can tentatively identify the main fields of short-run and long-run investigations as well as the points of contact between them.

In the short-run investigation the present agricultural policies are described under the prevailing economic conditions (Parikh, 1977; Csaki, 1978, 1979; de Haen et al., 1978). In the closed economic model of a country the food sector differs only in its degree of detail from the rest of the economy. In fact it is such an integral part of the economy that Figure 10 could represent any other sector without the slightest change.

Although this is a somewhat more detailed version of a national model from Figure 1 it is still oversimplified.

The main parts of this system are the blocks for production, exchange, income redistribution and spending, assessment of the nutritional situation, and government policy. Of these, the exchange part is the connecting module with other countries. The box labeled "international market" is just a dummy for a third dimension in the figure.

The linkage system, taking care of the exchange part, is based on the general equilibrium approach (Keyzer, 1977a, b, c; Keyzer et al., 1978). What is important to note here is that all the countries have to meet certain "linkage requirements" in order to be able to be linked with the system. The main requirements are the following. (1) The commodity list should be accepted. It is possible to introduce more commodities than there are on the commodity list but only those products which are defined by the list participate in the international exchange. (2) The time horizon will be 15 years and the time increment one year. (3) There is a one-year time lag after production decisions are made. Production is given at the time of exchange. (4) The models should be closed; the rest of the economy should be represented as one aggregated commodity. (5) Government policies should be explicitly formulated. (6) The models should behave as continuous nonsmooth excess-demand functions of international prices.

Within these restrictions much freedom is given to represent different national economies. Production might be represented by different methodologies (in fact almost all countries use their own methods) and with proper modifications the centrally planned economies can also be fitted into the system (Csaki et al., 1978).

Let us return to our reference system and summarize its shortcomings: (1) agriculture, being a part of the general structure, is hidden here; (2) in Figure 10 two dimensions are missing, namely international exchange and time delays; (3) a range of feedback relations among resources, technologies, and environment is also missing.

By turning to this last item we can identify the long-run problems. There are feedback relations in this field which should be investigated. In the short run it is quite safe to assume that renewable resources and environment will not be heavily affected by the production methods and that the shift in technologies will be slow and predictable up to the short-term horizon. However, in the long run we cannot rely on these assumptions. As soon as a long-run process is started, the short-run pressures in these interconnected fields begin to exhibit lives of their own and a slow long-run feedback mechanism begins to be felt. This in turn reacts through production on short-run economic processes. To use a somewhat naive analogy, the short-run economic system acts like a fast cogwheel which begins to move a big slow flywheel which later, under given circumstances, begins to take over the driving functions in the system. Technological developments, originally induced by labor or land scarcity, begin to develop autonomously once they have transformed the capital structure. This autonomous development forecloses more and more other technical options; i.e. "jumping" to another technical path will be more and more difficult. In addition, vicious circles may be created: e.g. scarcity of resources might lead to overexploitation of a technology which, through environmental deterioration, reduces the resources even further. Here is the field for our second task which we will try to reformulate this year. In the new task definition (Hirs, 1979) we try to use all the experience we have gained in the single, partial solutions developed for problems in the related fields of environment, resources, and technology (Csaki, 1977; Carter et al., 1977; Clapham and Pestel, 1978; Golubev et al., 1978). The first tentative ideas connected with this task are under development.

REFERENCES

Abel, M.E. (1975). The impact of U.S. agricultural policies on trade of the developing countries. In G.S. Tolley and P.A. Zadrozny (Editors), Trade, Agriculture, and Development. Ballinger, Cambridge, Massachusetts, pp. 21–56.

Carter. H.O., Csaki, C., and Propoi, A. (1977). Planning long-range agricultural investment projects: a dynamic linear programming approach. RM-77-38. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Clapham, W.B. and Pestel, R. (1978). A common framework for integrating the economic and ecologic dimensions of human ecosystems: Part 1 – General considerations, RM-78-29; Part 2 – Processes and problem chains within the natural stratum, RM-78-30; Part 3 – Policy, uncertainty, and analysis, RM-78-31. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Clark, C. (1967). Population Growth and Land Use. Macmillan, London.

Csaki, C. (1977). Dynamic linear programming model for agricultural investment and resources utilization policies. RM-77-36. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Csaki, C. (1978). First version of the Hungarian Agricultural Model (HAM-1). RM-78-38. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Csaki, C. (1979) Second version of the Hungarian Agricultural Model (HAM-2). WP-79-71. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Csaki, C., Jonas, A., and Meszaros, S. (1978). Modeling of centrally planned food and agricultural systems: a framework for a national policy model for the Hungarian food and agriculture sector. RM-78-11. International Institute for Applied Systems Analysis, Laxenburg, Austria.

FAO (1976). FAO Trade Yearbook 1976. Food and Agricultural Organization, Rome.

Golubev, G., Shvytov, I., and Vasiliev, O. (1978). Environmental problems of agriculture. I: Water-related environmental impacts of agriculture at the field level. RM-78-32. International Institute for Applied Systems Analysis, Laxenburg, Austria.

de Haen, H. (1978). The Food and Agricultural Model of the International Institute for Applied Systems Analysis. RM-78-24. International Institute for Applied Systems Analysis, Laxenburg, Austria.

de Haen, H., Schrader, J.V., and Tangermann, S. (1978). Modeling the EC agricultural sector: problem assessment, policy scenarios, and model outline. RM-78-23. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Hirs, J. (1979). An approach to the investigation of limits and consequences of food production technologies. Draft. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Jansen, (1975). Constructing Tomorrow's Agriculture. EEC Report. EEC, Brussels.

Johnson, D.G. (1975). Free trade in agricultural products: possible effects on total output, prices, and the international distribution of output. In G.S. Tolley and P.A. Zadrozny (Editors), Trade, Agriculture, and Development. Ballinger, Cambridge, Massachusetts, pp. 3–20.

Josling, T. (1975). World food problem – national and international aspects. Food Policy, 1(1):3–14.

Keyzer, M.A. (1977a). Linking national models of food and agriculture. RM-77-2. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Keyzer, M.A. (1977b). Analysis of a national model with domestic price policies and quota on international trade. RM-77-19. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Keyzer, M.A. (1977c). International trade policies in models of barter exchange. RM-77-51. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Keyzer, M.A., Lemarechal, C., and Mifflin, R. (1978). Computing economic equilibria through nonsmooth optimization. RM-78-13. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Klatzmann, J. (1975). Comment Nourrir Dix Milliards d'Hommes? Presses Universitaires de France, Paris.

Littlechild, S., Weber, R., and Young, H.P. (1979). Strategic models of world food production and trade. WP-79-58. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Neunteufel, M. (1977). The state of the art in modeling of food and agriculture systems. RM-77-27. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Parikh, K.S. (1977). A framework for an agricultural policy model for India. RM-77-59. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Popov, T. (1978). The general situation and main tendencies of food and agricultural development in the European CMEA member countries (1960–1975 and up to 1980). RM-78-51. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Rabar, F. (1976). Food and agriculture: global aspects of supply and demand. CP-76-7. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Revelle, R. (1974). Food and population. Scientific American, 231(3):160.
Schmidt, S.C. (1977). Assessment of existing and prospective world economic and food trends. RM-77-14. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Schmidt, S.C. and Carter, H.O. (1978). National and international food policies and options that impact on world trade and aid. RM-78-22. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Swanson, E.R. (1975). Classification of food and agricultural policies: objectives, instruments, and performance indicators. WP-75-151. International Institute for Applied Systems Analysis, Laxenburg, Austria.
University of California (1974). A hungry world: the challenge to agriculture. Summary Report of a Task Force Meeting. UCLA, Los Angeles, California.

DISCUSSION

In reply to a question by Kamrany, Rabar *explained that the coordination between the national models is effected by the modelers' actually working together: every few months the groups are convened at IIASA in a very tense workshop, often sitting at the computer together throughout the night! Part of the work consists in studying how the national models behave in the linked mode. One problem lies in the balance of payments since the monetary system as such is normally not modeled.*

Kellogg *asked how climatic variations (both short-term variations (e.g. a major drought) and long-term changes) are represented in the models.* Rabar *replied that the original idea of using a random procedure has been dropped; a scenario-type approach (e.g. considering simultaneous droughts in several major areas of the world) seems preferable. With regard to the long-run changes, exogenous assumptions could be introduced and their effects studied.*

Parker *asked how government policy aimed at influencing production, consumption, and/or trade is represented in the models.* Rabar *answered that neither endogenous nor exogenous treatment seems satisfactory: on the one hand, if government policies were completely endogenized the predictive value of the model becomes questionable since government policies will definitely change in reaction to certain developments; on the other hand, if government policies were completely exogenized hundreds of scenarios* *would become possible. The crucial aspect lies in finding the proper level of endogenization, for example, by reducing government policies to a few basic types which can be verified by running the models for a past period.*

Asked by Roberts, Rabar *outlined the treatment of "energy" in the model: it is true that "energy" is represented within the "rest of the economy"; however, it can be explicitly introduced in the production functions, whereby exogenous changes in energy prices will exert a joint effect on all sectors of the model. As to technical change, it has practically been ignored so far, given the medium-term time horizon of the model. In the next phase, however, the questions of what effects scarcities or abundances of resources will have on technical choices, and the feedback these choices will have on the environment and on resources themselves, will be studied.*

Steger *wondered why "environment" is being treated only exogenously.* Rabar *replied that environment plays a role (a) on a small geographical scale and (b) on a long-run time scale. In a medium-term model based on nations as units it is almost impossible to endogenize environment. It can be introduced as a constraint to identify short-run pressures plus their long-run effects.*

AIMS AND APPROACHES IN STUDYING THE "LIMITS AND CONSEQUENCES OF FOOD PRODUCTION TECHNOLOGIES"

Jaroslav Hirs
Food and Agriculture Program, International Institute for Applied Systems Analysis, Laxenburg (Austria)

1 INTRODUCTION

The task "Limits and Consequences of Food Production Technologies" is part of the structure of the Food and Agriculture Program of the International Institute for Applied Systems Analysis (IIASA). This task was started in 1980, with some preparatory work being done in 1979. The major aims of the Food and Agriculture Program as formulated in the draft version of the IIASA Research Plan for 1980–1984 are (1) to evaluate the nature and dimension of the world food situation, (2) to identify the factors affecting this situation, and (3) to investigate alternative ways on the national, regional, and global level to alleviate current food problems and to prevent future ones.

During the first period of research activities for the Food and Agriculture Program work focused mainly on the investigation of alternative national agricultural policies and their influence in the short run on both the international and the national level. In order to investigate these problems in an international context, and at the same time to consider the nations as basic (largest) economic units, a set of national models for selected countries was developed and linked together as a global system. This work, which is being continued on various levels of aggregation, is reported by Rabar in the preceding paper (this volume, pp. 95–113).

However, this work is being carried out under various assumptions, some of which would no longer be valid if the time horizon were to be extended. This is especially true in the case of technological change and environmental aspects. It was realized during work on national models that if the long-term development of the agriculture system was to be investigated then technological change would become one of the most important aspects, whereas in most of the short-term models there is assumed to be no substantial change in technology.

Environmental problems are similarly treated in the present national models, with the assumption that there is no feedback between agricultural activities and natural resources (water, soil) in the short run.

For this reason research activities were started on technological change and agricultural impacts on the environment. However, such activities cannot be carried out in isolation since the interaction between technological change, the environment, and resource use is of great importance in the long run. Thus the Food and Agriculture Program is now concentrating on the following complexes: (1) short-run problems (the investigation of appropriate policy measures, taking into consideration the present economic conditions in the countries and international market interactions); (2) long-run problems (primarily oriented towards investigations of the impacts of alternative paths of technological development, taking into consideration changing resource availability).

2 THE SITUATION

From a global viewpoint the food and agriculture system does not manage to achieve fully its main goal of providing the world's population with enough food. However, the causes of this are not global but rather country specific (where they are connected with the economic environment) or regional (geographically) specific (where they are related to the natural environment).

In addition to its main goal the food and agriculture system also has other objectives such as providing us with nonfood products which are used as inputs for nonagricultural activities in general. Since these products are obtained not only as by-products from processes oriented towards food production but also from separate production processes they may (and in fact do) compete with food production for the limited resources available.

In reality the performance of the food and nonfood (agriculture) production system has to reflect hundreds of requirements (demands) for hundreds of products, each with different priorities. These priorities and demands change over time. As well as this, the extent of the production required is strongly dynamic.

In the long-run development of the system we can observe the following phenomena: (1) a growing interdependence between food and agriculture and other parts of the economy; (2) an increasing sensitivity of the system to outside impacts owing to a more and more complicated internal structure and a growing number of interconnections; (3) a growing diversity of and a growing absolute level of demand for food and agriculture products; (4) an increasing variety of technologies for the production of individual products, which usually entails an increase in the synthetic (e.g. chemical) elements in the originally biologically based processes, which in turn often increases the extent of the negative impacts on the environment.

Nearly all the present specific problems exhibit at least one, and in many cases several, of these tendencies.

A considerable number of the questions being discussed in connection with the future development of the food and agriculture system are closely related to the problem of the stability and sustainability of the system. Questions – such as How can potential future production be influenced? How are natural resources and the environment influenced by the given agricultural activity and how dangerous could this be for the population? How flexible will the system be with respect to changes in the economic and natural environment? – become increasingly important in the long run, in addition to the basic question of how to meet global food requirements in a socially efficient way.

Obviously technological development plays a crucial role in the long run since the development and introduction of new technologies influence all the resource- or environment-oriented aspects. From this point of view, technologies are the most dynamic and active element within the system, an element which is a "product" of man's intellect and which is influenced strongly by society's increasing knowledge and experience. For this reason attention should be paid primarily to the development and influence of this element (but without the role of the others being forgotten).

Thus, if we formulate the problem as how to maintain the sustainability and stability of the food and agriculture system in the long run then the objective of the research activities is to identify how the various paths of technological development could influence the sustainability of the food and agriculture system in the long run.

Although a number of detailed questions can only be asked in relation to specific countries or regions, certain aspects of a more general nature are applicable to many countries and should therefore be focused on. How the energy problem can be affected by new technological alternatives in agriculture is one aspect that is urgent for nearly all countries. Resource problems could also be addressed: for example, what could be potentially the most scarce and limiting resource type when the various kinds of technological development in the future are considered?

From the technological point of view interest is centered on establishing which new technologies can be expected during the next 20–30 years and how they may influence both the field of energy and the sustainability of the system, particularly with regard to the environment.

3 THE APPROACH

In studying the problems of technological development various time horizons can be used depending on which aspects the research is focused on. The difficulty lies in the fact that a sufficiently correct description of the technological changes expected for about the next 20 years can be drawn up but the consequences of these changes with respect to natural resources (soil, groundwater) may have life cycles that are substantially longer than the aforementioned time horizons.

It is therefore assumed that two interconnected approaches will be used in our research activities, the one focusing on an analysis with a time horizon not exceeding a period of 20–25 years (being at the same time disaggregated) and the other focusing on the analysis of those aspects for which a time horizon longer than 25 years is necessary.

Research activities in the first direction will be characterized by a relatively detailed description of the various paths of technological development that are expected to be available within the given time horizon as well as by relevant details of individual kinds of resources. In this case the quantitative analysis of various alternatives can be carried out for particular countries or geographical areas.

Considering the different socioeconomic conditions in individual countries and at the same time the large variety of natural resources it is obvious that no one uniform strategy of technological development can be found or even exists but rather that the desirable (appropriate) development has to be specified in accordance with both the economic and the natural environment. Thus units that are homogeneous from both points of view must be specified, which means that each country/region under study has to be divided into smaller parts as basic units for the purposes of investigation.

This approach has already been applied by various authors for a deeper analysis and consideration of natural resources as a basis for economic conclusions on the country level. For the purposes of the task formulated this approach seems to be the most appropriate.

An investigation of all countries or groups of countries in region-specific detail would enable us to arrive at a picture of the situation at the global level. However, such a detailed investigation is far beyond the resources available for research.

For this reason several case studies will be carried out in different regions or countries. We assume that these studies will be carried out in both highly developed and in developing countries. The studies will possibly be so organized as to cover systems with different socioeconomic conditions.

In these studies attention will be paid to the various paths of technological development which may be achieved given limited resources. Special emphasis will be placed on land and energy. A further aspect of importance is the consideration of the environmental consequences of various alternative development paths including both environmental impacts on natural agricultural resources (especially land) in the future and impacts which are felt outside the agricultural sector (e.g. groundwater pollution).

4 METHODOLOGY

In order to carry out the proposed studies a modeling approach will be adopted. A general methodology is presently under discussion. We aim to set up a system of modules for use in the generation of the various alternatives for the development of the agricultural system in a selected region. Figure 1 shows the structure of the proposed system in simplified form.

The recursive character of the system is indicated. The data base contains information about both the natural resources and the economic conditions at the beginning of the time period. Using this information as a starting point the alternative yield levels and the relevant input levels (e.g. water and fertilizer in crop production) will first be generated. These in turn will serve as a base for the generation of a set of alternative technologies for the production of each commodity. Each of the alternative methods generated will in turn have some environmental impacts, which also need consideration. In this way the generation of alternatives and the use of the data base (natural resources) will aid the estimation of the "environmental coefficients".

All this information on the alternative technologies available will serve as one of the inputs for the decision module. However, further information (e.g. restrictions, prices, criteria functions) is also required. In this module linear programming will be employed to find the optimal combination of technologies for use within the given period.

With the results of this module data bases for the next period can be updated. Although not separately represented in the figures, these will include the estimation of the impacts of the selected technologies on natural resources as well as the updating of economic parameters. The linkage of the systems of interest with the rest of the economy or with other regions has to be simulated at this point. In this system the basic time

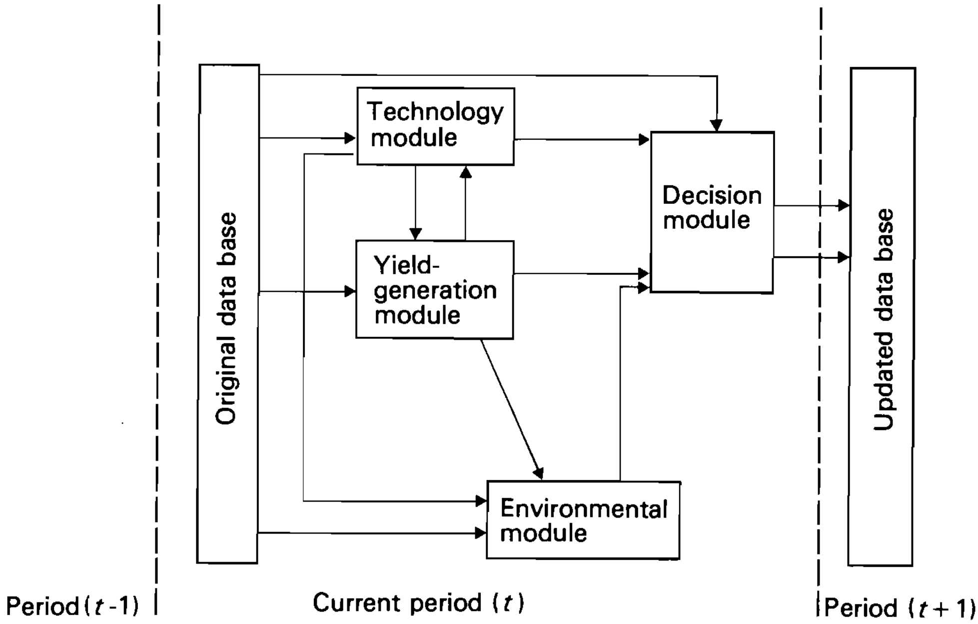


FIGURE 1 An outline of the structure of the proposed model system.

increment is expected to be one year; however, some of the parts (e.g. yield generation) may go into more detail and therefore may use shorter time increments.

The model system that is being developed will be used for the investigation of the long-term consequences of the various alternatives for technological development and the simulation of various scenarios with respect to resource availability. Some parameters may be derived from the global model system of the Food and Agriculture Program. In the same way the insight that is gained into long-term consequences may aid in establishing some of the limitations and parameters needed for the global system. A comparison of selected aspects of the two systems is given in Table 1.

TABLE 1 A comparison of selected aspects of the two model systems of the Food and Agriculture Program.

Aspect	Short-term (Task-1) model system	Long-term (Task-2) models
Time horizon investigated	5–10 (possibly 15) years	20 years and beyond
Unit (geographical)	Country	Regions within the country
Natural resources		
Land	Not separately expressed in the simplified system	Land classes ↘ to be considered
Water	Aggregated in detailed models	Watersheds ↗
Level of analysis	Country → global	Regions → national
Environmental aspects	Not included	Considered at the regional level
Interaction with national economy, market reactions	Endogenously (on the country level)	Not endogenously, considered as given or simplified

DISCUSSION

In reply to Kuzmin, Hirs *stated that the model system would be of a recursive nature, having a linear programming part to enable the selection of an optimal combination of technologies in a given year and a dynamic part for the simulation of the physical processes. It is assumed that the tradeoff between the demand for a production increase and environmental quality be analyzed over a longer time horizon.*

Quance *described the study carried out in the United States dealing with the relation between productivity growth and research expenditure. Extended collaboration with experts resulted in conclusions with regard to the expected breakthrough in the field of agriculture and the possible consequences.*

Roberts *suggested that the required food production (demand) for a region should be endogenized.* Hirs *mentioned the high degree of interdependency between the regions (detailed studies) where even factors such as transportation problems and cost might play an important role. This would be shown as exogenously given targets at the first (simplified) stage but could be included in more detail at a later stage.*

Sydow *asked which environmental components would be included in the study. In reply* Hirs *pointed out that detailed specification would be needed later with respect to the conditions in the individual regions and mentioned water pollution and erosion as the next conditions to be specified.*

Nishiwaki *again brought up the problem of comparing the benefits of agricultural technologies with environmental effects.* Hirs *pointed to the difficulties in this direction and stressed that the research planned would take into consideration the social point of view and not that of the individual farmer.*

In reply to Steger, Hirs *stated that experts from different nations would be involved in this work. Collaboration is essential in order to permit correct specification not only of environmental aspects to be considered but also of the technological alternatives, especially where weighting factors on the preference scale are to be developed on the basis of the experts' judgement.*

THE THAILAND MODEL AND ITS AGRONOMIC LINKAGES

Doeke C. Faber and H. van Asseldonk
Centre for World Food Studies, Free University, Amsterdam (The Netherlands)

1 INTRODUCTION

In this paper we present an outline of the modeling effort of the Centre for World Food Studies. We give an overview of the Thailand model as it is now being constructed and show the agronomic input in particular.

The present modeling effort is a continuation of the research work begun five years ago which has become known as the Model of International Relations in Agriculture (MOIRA). This study differs from earlier studies of the world food situation and prospects in its combination of information on soils, climates, and agricultural potential with a rigorous economic analysis in an equilibrium framework. The merit of analysis using MOIRA is its capacity to trace the effects of alternative national and international policies.

Some of the characteristics and assumptions included in MOIRA-1 are as follows. (1) The model is not country specific. Based on statistical information on 106 geographical national entities, central tendencies and parameters are estimated using cross-country estimating procedures. Thus the model contains relations which are found to apply on average to all countries but to no country in particular. (2) The model reduces all agricultural outputs to the one common denominator of consumable protein. (3) Capital–labor substitution is not differentiated between various regions of the world or between different agricultural activities. (4) The "cross-country one-commodity specification" permits the specification of only one set of policy instruments and objectives: income parity and price setting/quotas.

Some policy recommendations reviewed by MOIRA 1 can be summarized as follows. The rich countries must significantly reorient their agricultural policies in order to adapt the volume of their foreign trade in food to an international market development which is more conducive to food production in the developing countries. In turn the developing countries must change their income distribution in favor of the agricultural sector in order to cut down their dependence on food imports and to reduce the extent of hunger.

Some of the foregoing points suggest elements of the present work program: namely (a) the definition and modeling of nation-states, (b) the inclusion of specific crops and commodities that later are to be aggregated to adhere to the specifications of IIASA's Food and Agriculture Program (see the papers by Rabar and by Hirs, this volume, pp. 95–113 and 115–120, respectively), (c) the inclusion of a savings–investment model. However, the main goal remains the scientific study of the global food situation and its prospects. In addition, the effort must include the all-important linkage between economic–agronomic and physical factors.

2 THE THAILAND MODEL – A GENERAL OUTLINE

The model distinguishes five regions, with subregions on the supply side. For each of these regions, excluding Bangkok, three groups of farmers are recognized: small farmers (including farm workers), medium farmers, and large farmers. For each region three groups of nonfarmers are distinguished: poor, medium, and rich people. Demand is expressed in terms of the IIASA classifications. It is assumed that nonfarmers produce marine fish, industrial forestry products, and nonagricultural products. Farmers produce commodities which correspond to the IIASA 19-commodity classification. The time period for which the model will be solved is one year. The model is a system of dynamic equations which describes supply, demand, income, and price formation. Supply adjusts to prices with a one-period lag.

The model follows a general equilibrium approach with the following main properties.

(1) The economy is divided into groups of households that are both producers and consumers. This allows endogenous analysis of income distribution. For each of the groups production and demand are modeled separately.

(2) The interactions between these groups take place within the policy environment set up by the government and within an international policy framework (Figure 1).

(3) During the current period production is predetermined. Therefore at the beginning of each period each income class has a given endowment of commodities. This endowment is the result of the production decisions of the previous period. These production decisions are modeled as a linear program that maximizes expected income given a particular stock of resources.

(4) The exchange module determines the equilibrium price, i.e. the price at which all domestic markets are cleared. At the same time all budgets balance, including the government budget and the balance of payments. The exchange module uses a complete system of demand equations for each income class.

(5) The market-clearing process is influenced by international conditions and government policies. The government tries to realize price targets for certain commodities. This can be done by imposing quotas on international trade and by adjusting government demand. The government can also try to realize certain income-distribution objectives through its taxation policy. International trade takes place at given world market prices; any divergence between domestic and world prices accrues to the government.

From one period to the next several structural variables are adjusted. This is to represent the dynamic aspects of the economy. The most important variables are (1) migration and related labor availability, (2) policy targets, (3) capital stocks, and (4) coefficients within the production or demand model that represent long-term changes.

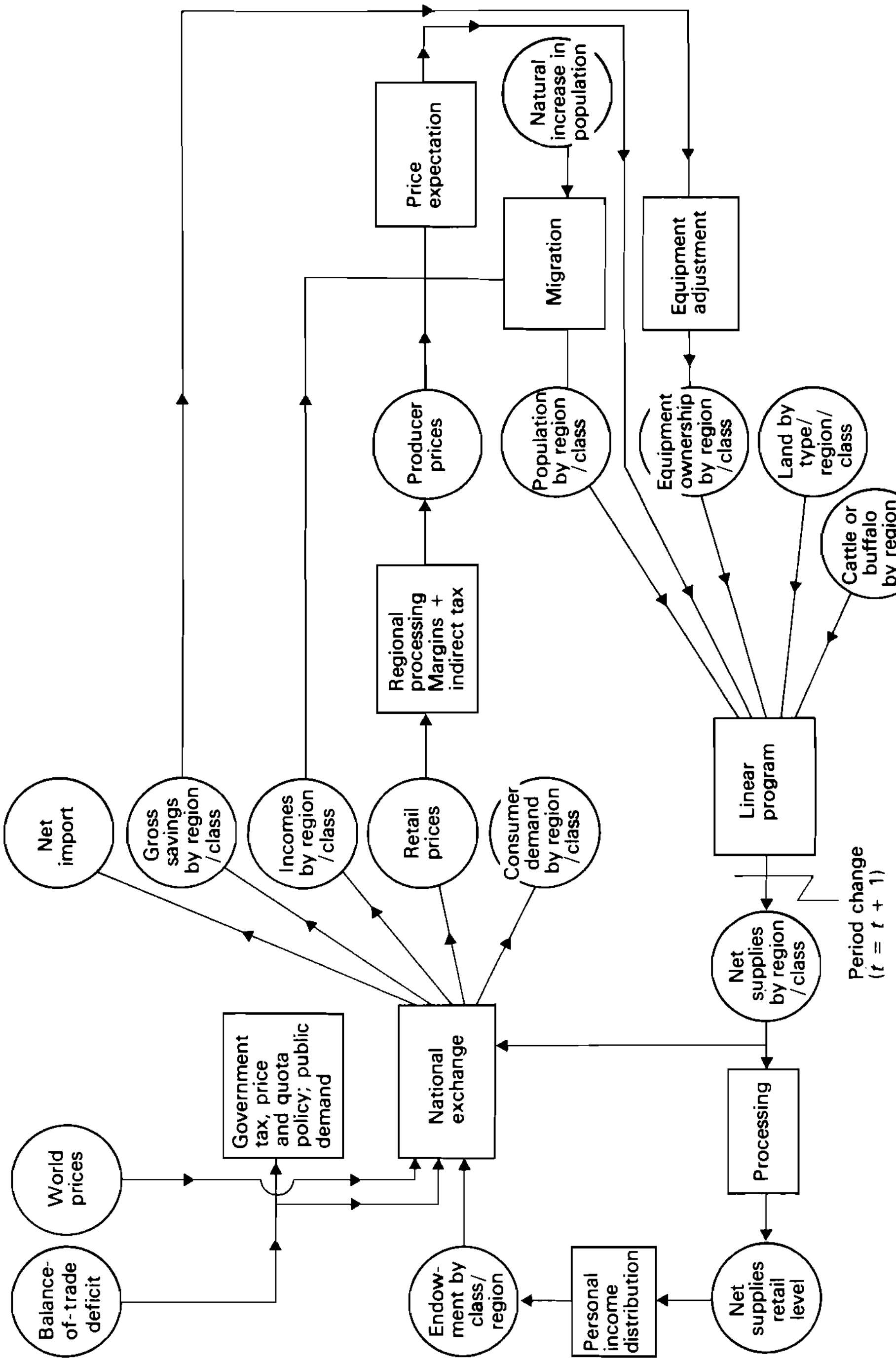


FIGURE 1 A flow chart of the Thailand model.

3 THE AGRICULTURAL MODULE

The agricultural sector will form the major component of the Thai national model. The structure of the model consists essentially of the modeling of a number of representative farms in a recursive linear programming framework.

Six agricultural production regions are distinguished on the basis of a number of homogeneity criteria, namely, soil and climatic characteristics and farm types. In addition, three farm sizes are defined within each of these regions to meet possible future changes in technology. It is assumed that the resources available to the individual farmer are of paramount importance for his future development. Finally the regions are defined in such a way that they can be identified with administrative units.

The six regions and three farm sizes will result in 18 linear programming models, each characterized by available physical and other resources such as land, labor, and capital. The 18 models will be aggregated by region. A number of regional constraints will represent interactions between the different farm sizes within a region. The production activities (livestock and crops) to be included in each of the linear programming models are both the (currently) observed and possible future production enterprises. The former will be defined by statistical and production data while the latter will be based on agronomic and economic criteria such as land capabilities, climatic and other variables, and production costs. Other activities are hiring, buying, and selling activities (including labor). A nonagricultural production activity has been included to represent the capital-extensive cottage industry.

The livestock and crop sectors will be linked via the animal draft and feed requirements. Livestock will use crop residues and fallow and nonharvested land for its roughage requirement.

The interactions between farm sizes within a region are expressed by the exchange of labor and draft power for purchasing power. It is useful to note that the exchange of labor is a one-way process; i.e. the small and landless farmers will offer their labor to the medium and large farmers. The labor constraints in the model will be on a monthly basis.

Within each farm size two or three "technologies" are distinguished. The differences between these exemplify the various methods of tilling, the level of fertilizer and pesticide application, and the methods of harvesting. The upper limit of most resources is set by the physically available quantities (e.g. for land) or the natural reproduction rate (e.g. for livestock). Other resources are bounded by the dictates of the general Thai model (e.g. imports and credits).

Agronomic information supplied by the Wageningen group (see the paper by Driessen, this volume pp. 149–155) will be incorporated in the model of Thai agriculture as shown in Figure 2. Input–output relations are considered in a three-level hierarchical approach as follows. (a) Yield levels are handled as dependent variables in relation to water and energy constraints, on the assumption that they are not constrained by levels of nutrients and other inputs. (b) Yields are considered under conditions of nutrient constraints but other inputs not constraining yield levels are used at this stage as independent variables to derive the required quantities of material inputs (e.g. fertilizer and pesticides). (c) The fieldwork requirements such as yield protection, harvesting, and land preparation follow from calculations based on data from (a) and (b). Substitution is assumed to be possible between labor, machinery, and draft animals.

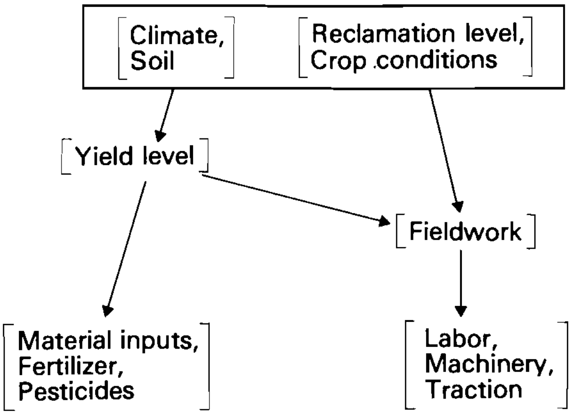


FIGURE 2 Schematic representation of the incorporation of agronomic information in the model.

The interface with the rest of the model will represent the dynamic aspects of the model. The exchange module yields a set of annual producer prices. On the basis of these prices the farmer will formulate his planting intentions for the next season. The migration module yields next year's available labor supply in the various sectors (e.g. agriculture, rural nonagriculture, and urban). Natural population growth and migration from the agricultural to the nonagricultural sectors will be endogenous in this module and will represent the main causes of shifts in labor availability. The investment module represents government policy and action in the field of land-reclamation activities such as irrigation and other water-management projects as well as new land development in the marginal areas. Finally, the exchange module – as a result of supply and demand – will yield the amount of savings in the agricultural sector.

In the next section we give a detailed outline of the manner in which the agronomists and soil scientists are proceeding.

4 THE AGRONOMIC APPROACH TO AGRICULTURAL PRODUCTION

The Wageningen approach can be schematically represented as follows (Figure 3). Three main characteristics can be distinguished: (i) regions, (ii) land classes, and (iii) exogenous variables. The regions determine the climatic variables while the land classes determine the soil-related variables. The exogenous variables are reclamation, crop pattern, natural fertility, and technology. These variables are then ordered and the system is solved hierarchically. We will now examine the various sections of Figure 3 more closely.

a–b. The climate determines the amount of solar energy influx per unit area of each crop and serves as the ultimate constraint on the possible level of dry-matter production. The energy influx is determined on the basis of latitude, day length, angle of incoming radiation, and degree of cloudiness.

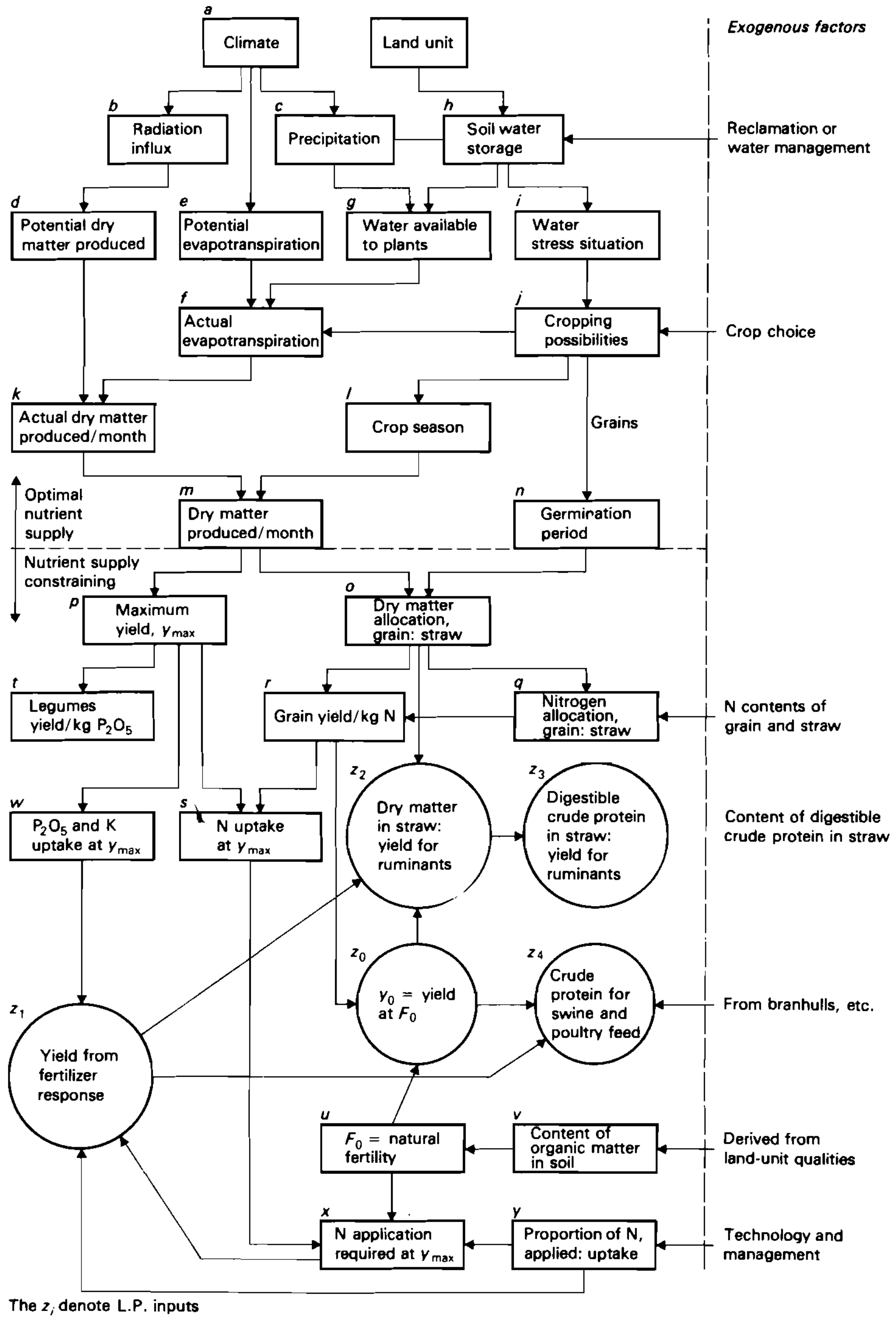


FIGURE 3 Schematic representation of the agronomic production model.

a–e–g. Precipitation determines in general the availability of water for a plant. The actual water availability in the root zone of a standard crop (because of root depth) can also be influenced by water that has been stored in the soil.

e–h–i. An accounting system is used to register the amount of water (in millimeters) stored in the soil and depends on soil type, reclamation level, and precipitation surplus. In the case when the soil is saturated and drainage is insufficient the model disqualifies the soil as being unsuitable for the production of crops that are sensitive to water stress.

b–c–d. The incoming energy *b* together with wind velocity and relative humidity determines the potential evapotranspiration of soil and crop (*c*) and the potential dry-matter production of C_3 and C_4 crops. C_4 crops (sugarcane, sorghum, and maize) have a larger biomass production per unit of incoming radiation because of more efficient photosynthesis.

c–g–j–f. The actual evapotranspiration is the evaporation (expressed in millimeters of water per month) that can in fact take place under the local water supply regime. Under optimal water conditions *f* will be equal to *c* ($f = c$). If the stored water supply cannot compensate a water deficiency or the crop growing stage prevents full transpiration then $f < g$.

d–f–k. The potential dry-matter production based on the energy availability will now be decreased on the basis of the relationship of actual to potential evapotranspiration. This yields the actual dry-matter production in kilograms per hectare per month for C_3 and C_4 crops.

j–l–n. The water model and the exogenous crop choice determine which crops will be considered. These crops have known characteristics such as length of growing season and germination period (i.e. the start of the generative period). Since there are usually many crop varieties available a choice may have to be made in order to select the variety best suited to the local conditions of water availability and day length.

k–l–m. Dry-matter production *m* of the selected crop is determined by adding the actual dry-matter production of a standard crop each month during the growing season. However, as long as the field is not covered completely (the first 3–6 weeks, say) or if the plant is in the ripening stage where the photosynthesis decreases sharply compared with a green complete-covering crop, a discount will be applied.

m–p. From *m* we obtain the dry-matter production of a specific crop under specified conditions of the water and energy supply. So far the nutrient supply has been assumed to be optimum. This yield is called y_{max}. The yield of sugar, carbohydrates, or fiber can be calculated from the dry-matter production using a constant conversion factor.

m–n–o. Every cereal crop has its own level and distribution of dry-matter production between straw and grain. Here we assume that cereals produce dry matter during the vegetative period solely as straw and during the generative period solely as grain. This results in the grain/straw ratio.

o–g–r. Next the relation between production and nutrients is introduced into the model under the precondition that grain and straw should contain a minimum amount of nitrogen (N). We assume a minimum of 1% N in the grain and 0.4% N in the straw. Given the grain/straw ratio of the dry matter, the nitrogen allocation and thus the grain yield per kilogram of nitrogen uptake is estimated. The latter can be defined as the nitrogen response that determines angle α of the crop line considered (Figure 4). If a crop is grown for its starch or sugar content the yield is calculated on the basis of the total dry-matter

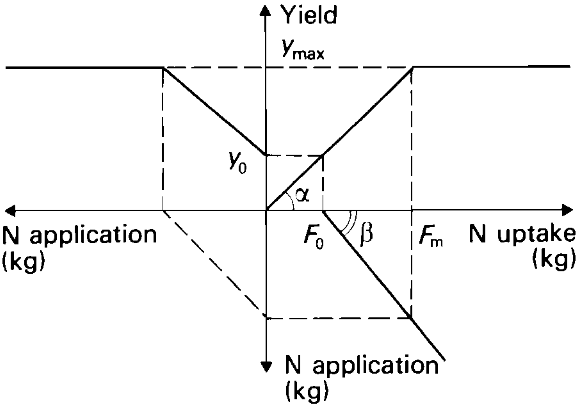


FIGURE 4 The relationships between nitrogen uptake and yield, between nitrogen application and uptake, and between nitrogen application and yield.

production during the growing period minus a percentage of residues; i.e. the two growing stages are not differentiated.

p–t. For legumes the yield–nitrogen relation is different because these crops have the capacity to fix nitrogen from the air during the growing season. The yield of these crops is therefore related to the available phosphate in the soil. Hence an assumption is made about the percentage of phosphate in the dry matter of the crop in order to find the yield level for a given phosphate availability.

p–r–w. From the angle α and y_{max} we determine the nitrogen uptake F_m under optimal conditions (see Figure 4).

r–u–v. The organic-matter content of soil (v) determines the natural fertility F_0 expressed in kilograms of available nitrogen per hectare during the growing season. From F_0 and α the yield y_0 without fertilizer can be determined. The natural fertility has been calculated using soil data.

u–y. The efficiency line of fertilizer application and fertilizer uptake in the fourth quadrant is determined by the natural fertility of the land and the level of technology or management of the farmer. It is assumed that the level of technology (e.g. the matter of application, weed control, water control) can change the slope.

s–u–x–y. From the difference $F_m - F_0$ and the slope β the level of nitrogen applied at y_{max} can be calculated (see Figure 4).

p–w–x. Throughout it is assumed that in the yield–nitrogen relation there is no deficiency of phosphorus or potassium. At high levels of nitrogen application phosphorus and potassium levels are assumed to be increased by corresponding fertilizer application.

x–y–z. The yield–nutrient relation is now determined to be within the limits made on either side.

DM (straw). The production of straw yields dry matter (*DM* (straw)) and the amount is calculated from the grain/straw ratio o and the yield y_0.

DCP (straw). *DCP* is the quantity of Digestable Crude Protein for cattle (bovines). It is determined by the protein content of the straw and its digestibility by ruminants as well as the quantity of straw produced.

CP feed. The Crude Protein (*CP*) is the amount of protein available for swine and poultry. The quantity is determined by assuming a constant relation between grain and *CP*. This relation assumes that parts of the plant (bran, hulls, shells, etc.) are not suitable for human consumption but can be digested by animals.

The specific fertilizer response z_0–z_1–z_2 determines the straw and protein production. Even from the rather simple diagram of Figure 3 it can be seen that an enormous amount of work goes into each component of the model. Close interaction between agronomists, soil scientists, and physical geographers is required to generate useful results and equations that can be included in the linear programming model. At all stages there is close cooperation with agricultural economists, who eventually have to incorporate the Wageningen end results ($z_1, z_2, \ldots, z_5$) in the programming model. To illustrate the foregoing approach an example of how a rice yield is generated, together with the required inputs, is given in the Appendix.

5 CONCLUDING REMARKS

The main goal of the Centre for World Food Studies is to make a policy-oriented contribution to the analysis of world food problems and prospects. The modeling effort that is now under way combines information on soils, climates, ecological factors, and agricultural potential with a detailed model of the individual country's economy. In this paper the Thailand model is presented as an example of the Centre's efforts to construct models with original methods to represent the all-important agricultural sector with more detailed and accurate information concerning the physical process of agricultural production. To incorporate the wealth of data generated in this manner new algorithms which exploit the specific structure of the agronomic information are under development at the Centre; another important requirement is that these new algorithms must be designed to keep the linear programming model to a reasonable size.

APPENDIX: AN EXAMPLE OF THE GENERATION OF RICE YIELDS: RAIN-FED PADDY IN NORTHEAST THAILAND

Table A1 gives some data on rain-fed paddy in northeast Thailand. The rice cropping data are as follows: June 15, transplant; October 1, germination; November 15, harvest. Dry-matter production results from the addition of monthly dry-matter production adjusted by the following factors: 0.25 for June 15–30 (coverage correction); 0.5 for July 1–31 (coverage correction); 1 for August 1 to October 15 (no correction); 0.25 for October 16 to November 15 (ripening correction). Dry-matter straw production is

$$900 + 3700 + 7200 + 6500 = 18{,}300\,\text{kg ha}^{-1}$$

Dry-matter grain production is

$$4875 + 1475 = 6{,}350\,\text{kg ha}^{-1}$$

The grain/straw ratio is therefore 0.35.

TABLE A1 Some data on rain-fed paddy in northeast Thailand.

Factor	January	February	March	April	May	June	July	August	September	October	November	December
Rainfall (mm)	10	30	45	90	190	160	160	190	240	120	30	5
Potential evapotranspiration (mm)	150	160	195	195	180	160	160	150	140	150	140	130
Potential dry-matter production P_3 (t ha^{-1} month^{-1})	6.2	6.1	7.0	7.2	7.7	7.2	7.4	7.2	6.5	6.5	5.9	5.8
Soil water storage (mm)	–	–	–	–	10	10	10	50	150	120	10	–
Actual evapotranspiration (mm)	10	30	45	90	180	160	160	150	140	150	140	15
Actual dry-matter production (t ha^{-1} month^{-1})	–	1.2	1.6	3.3	7.7	7.2	7.4	7.2	6.5	6.5	5.9	0.8
Rice production (wet season) (kg ha^{-1})	–	–	–	–	–	900	3700	7200	6500	4875	1475	–

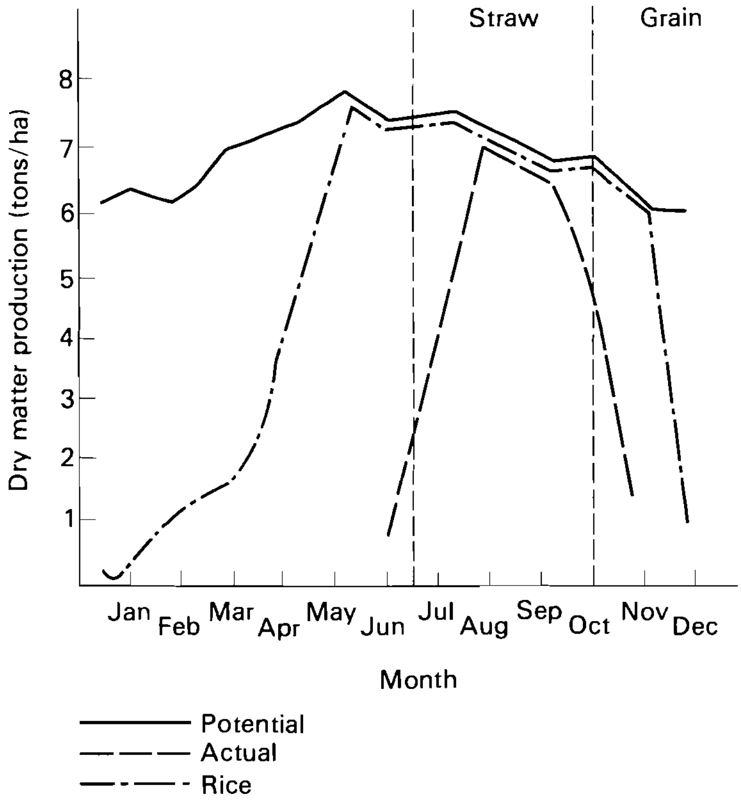


FIGURE A1 The potential and actual monthly production of dry matter and the monthly production of dry matter from rice in northeast Thailand (in tonnes per hectare).

The monthly production of dry matter in tonnes per hectare is shown in Figure A1. We assume in the case of rice a nitrogen content in grain of 1% and in straw of 0.4%. Given a grain/straw ratio of 0.35, the nitrogen-extraction rate is 2.15 kg per 100 kg of rice or inversely 1/2.15 = 46.5 kg of rice per kilogram of nitrogen uptake (β). Assuming the natural fertility to be 15 kg N ha^{-1}, $y_0 = 46.5 \times 15 = 700$ kg of dry matter per hectare. Taking into account the (pre)harvest loss of 25%, y_{max} is $0.75 \times 6350 \times 1.18 = 5620$ kg of rice per hectare (conversion factor of dry matter to rice = 1.18). In this situation, given the land unit, reclamation level, and technology, the nitrogen application/uptake ratio is assumed to be 2.5 (α). To obtain the yield of 5620 kg ha^{-1}, 5620/46.5 = 121 kg N ha^{-1} uptake is required. Given the natural fertility of 15 kg N ha^{-1}, an application of $(121-15) \times 2.5 = 265$ kg N ha^{-1} is required as fertilizer gift. The relations between nitrogen application, nitrogen uptake, and rice yield are shown in Figure A2.

For livestock fodder and feed production, the quantity of dry-matter straw = 700/0.35 = 2000 kg ha^{-1}, DCP is 2% of dry-matter straw (= 40 kg ha^{-1}) (2% is based on the crude protein content of rice straw for ruminants), and the CP feed to swine and poultry is 3.24% of y_0 = 22.7 kg CP ha^{-1} (3.24% is based on the percentages of hulls–bran and polish residues of grain and their crude protein contents).

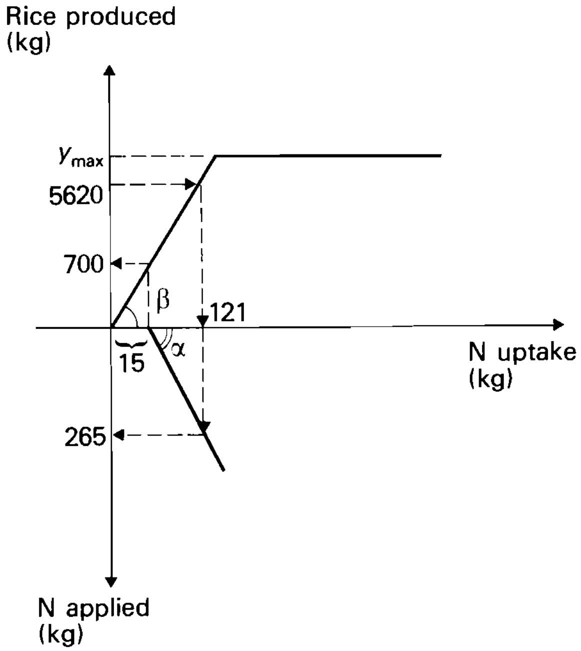


FIGURE A2 The relationships between nitrogen application, nitrogen uptake, and rice yield in northeast Thailand.

The fertilizer-response and production data are as follows: a 1 kg nitrogen gift results in

46.5/2.5 = 18.6 kg dry-matter rice grain

18.6/0.35 = 53.2 kg dry-matter straw

53.2 x 0.02 = 1.06 kg DCP for ruminants

18.6 x 0.0324 = 0.60 kg CP feed for swine and poultry

DISCUSSION

Asked by Steger, Faber *confirmed his view that in model building one can either try to be wide (to cover a large number of countries, sectors, commodities, etc.) or try to be deep (to identify the underlying interactions) whenever manpower resources are limited. In his modeling work the emphasis was on being deep. Therefore one should not use "cost per model" as an efficiency criterion. Once deeper understanding has been reached by analyzing one selected "target country" the findings can to a certain extent be used in constructing other country models.*

Asked by Parker *whether the rather complex Thai model has been verified,* Faber *replied that the model has only just barely been completed. As to subsistence farming, the model assumes that the farmers do not consume any more than they can produce themselves, always having a chance to sell an excess on the market.*

ESTIMATION OF CROP YIELD POTENTIALS AS AFFECTED BY AGROECOLOGICAL CONDITIONS: AN ATTEMPT TO PREDICT THE YIELD POTENTIALS OF THE MICRO-ECOLOGICAL REGIONS OF HUNGARY FOR THE YEAR 2000

Zs. Harnos
Bureau for Systems Analysis, ul. Victor Hugo 18–22, Budapest (Hungary)

B. Győrffy
Agricultural Research Institute of the Hungarian Academy of Sciences, P.O. Box 19, 2462 Martonvasar (Hungary)

1 INTRODUCTION

In recent years increasing attention has been focused throughout the world on the assessment of natural resources and the possibilities for their utilization. Today these assessments include not only energy resources and raw materials but also the so-called "biological resources". It is particularly important to be familiar with the interaction between the natural environment and plant and animal production in order to discover the hidden reserves in biological resources, their possibilities, and their limitations. Biological resources occupy a special place among natural resources owing to their renewability and, by rational utilization, their potential can even be increased.

In Hungary work on the estimation of agroecological potentials started in 1978 on the initiative of the Hungarian Academy of Sciences and is still in progress under the direction of its Deputy Secretary-General, Academician Istvan Lang. Because of the importance of the subject five supreme authorities, 15–20 research institutes, universities, computing centres, etc., and about 400–500 scientists are involved in solving the problem. The work was scheduled for completion in the spring of 1980 and thus it can serve as a basis for the long-term economic plans that are now about to be drawn up.

2 OUTLINE OF AIMS AND METHOD

The model to be presented has been developed for the purposes of regional planning but, with regard to its methodology, it can also be used to solve global modeling problems. The assessment comprises estimates of crop yield potentials at the beginning of the next

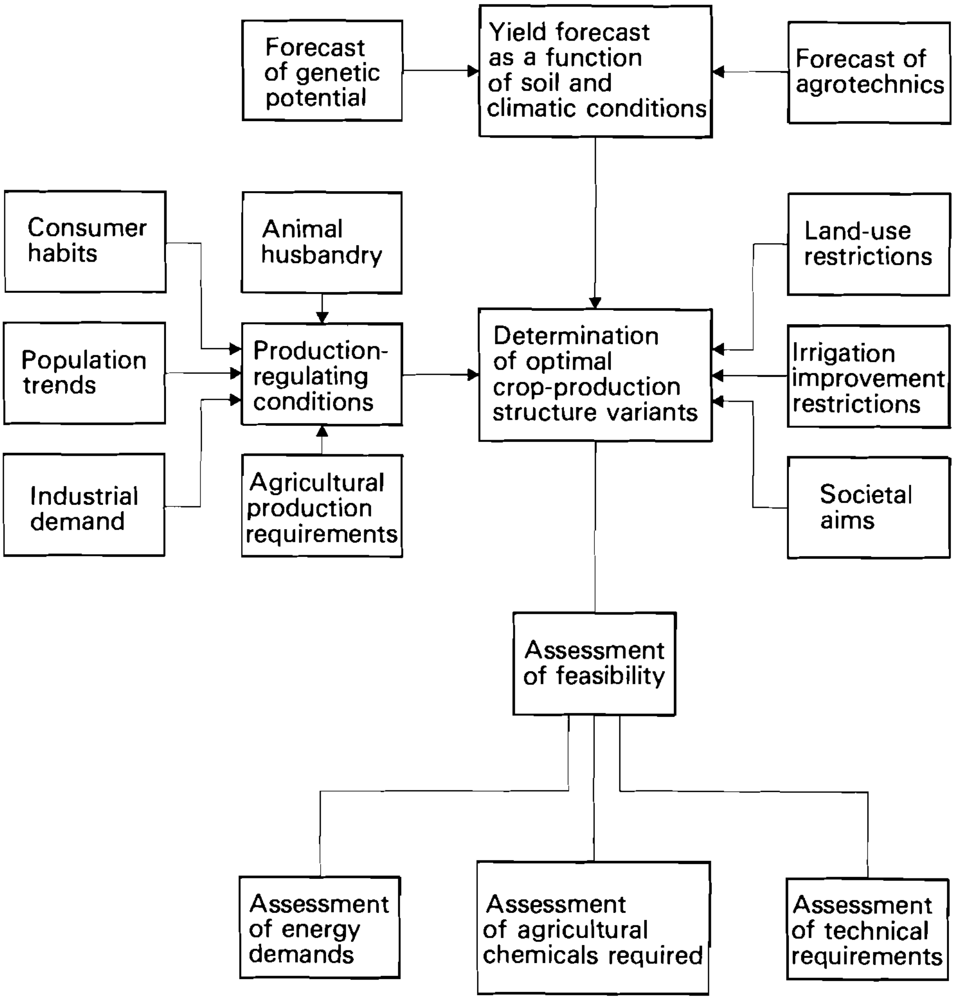


FIGURE 1 The main interrelationships in crop production.

century since basically it is the quantity and composition of crop yields that determine the overall results attained in animal husbandry. The expected total crop yield potentials in the year 2000 will be determined by three groups of factors: (1) the yields attainable under the given natural conditions of the country using advanced technology; (2) the proportion of agricultural land, its productivity, and the resources available for its modification (irrigation, improvement); (3) the demands of society for agricultural production.

Figure 1 shows the main interrelationships in the overall crop-production process.

In the present paper we shall deal only with the first group of factors mentioned above, namely, the yields attainable under the given natural conditions in Hungary using advanced technology: therefore, we will work with the following hypothetical situation. The agroecological crop potentials of the country that are expected for 2000 were calculated on the assumption that, in 20–22 years' time, basically the same procedures as those in use now will be used to produce the primary food materials. We assume that crop production will take place nearly exclusively under field conditions (partly under plastics or greenhouses). No fundamental or completely new "breakthrough" results in plant breeding, or fertilizer or water usage methods, which could put plant production on completely new bases, will be considered. Thus the calculations are completely aimed at the "safe alternative", i.e. at a case that will occur with a high degree of probability and worse than which cannot reasonably be expected. Thus, any significant and beneficial scientific achievement that may unexpectedly occur will only improve the situation.

The major aim of the study is to determine what yields the natural environment (precipitation, temperature, soil, relief, water supply, etc.) and the genetic potential of the various crops will allow in the year 2000. As neither the environmental conditions nor their areal distribution will change fundamentally, the aim should be to utilize the inherent possibilities in the most expedient way. Obviously, the partial modification of environmental factors (improvement, irrigation, etc.) should also be considered.

The technique of using purely mathematical econometric methods had to be rejected since at present we understand very few of the functional relationships between the factors affecting crop production and yield results, and we cannot expect to discover all these relationships in the near future. The relationships that are at present understood concern the effects of certain specific factors and sometimes the limitations that they impose. The study of climatic effects or those of fertilizers may fall into this group. The results of such studies may influence the forecast but cannot replace it.

For the reasons mentioned, in preparing the forecast a combined expert inquiry with written–oral feedback was used, based on plentiful information and statistical analysis.

The factors affecting field crop production can be divided into three groups: (1) crop-management parameters (labor, machines, fertilizer, etc.); (2) genetic properties; (3) environmental conditions. This list does not imply a ranking; the three groups cannot be separated from each other and can be considered only as interdependent. We will deal in detail with the environmental conditions, but this is based on two previous forecasts. (1) A forecast was prepared in 1978 on the technical–technological parameters to be expected in 2000. (2) A separate study was made on the expected genetic potential of field crops; this dealt with the analysis of the yield capacities of the 12 most important field crops and the roles of the factors influencing them. This latter study gave forecast of the genetic potential of each species (the maximum biomass producible with the species in a nonlimiting environment), the potential yielding ability of each species (the maximum economic yield producible with the species in a nonlimiting environment), and the maximum yield which can be attained in practice (the maximum economic yield attainable with the species). Obviously this type of work cannot replace the forecasts for microecological regions but it can greatly influence and promote their preparation.

The environmental conditions are determined by many parameters including the relief, the type of soil, its physical and chemical condition, the depth of humus-layer precipitation, heat unit, the hydrological conditions, and irrigation. This list is by no means complete but it demonstrates that if differentiations were made according to every relevant parameter an immense number of agroecological region types would be obtained.

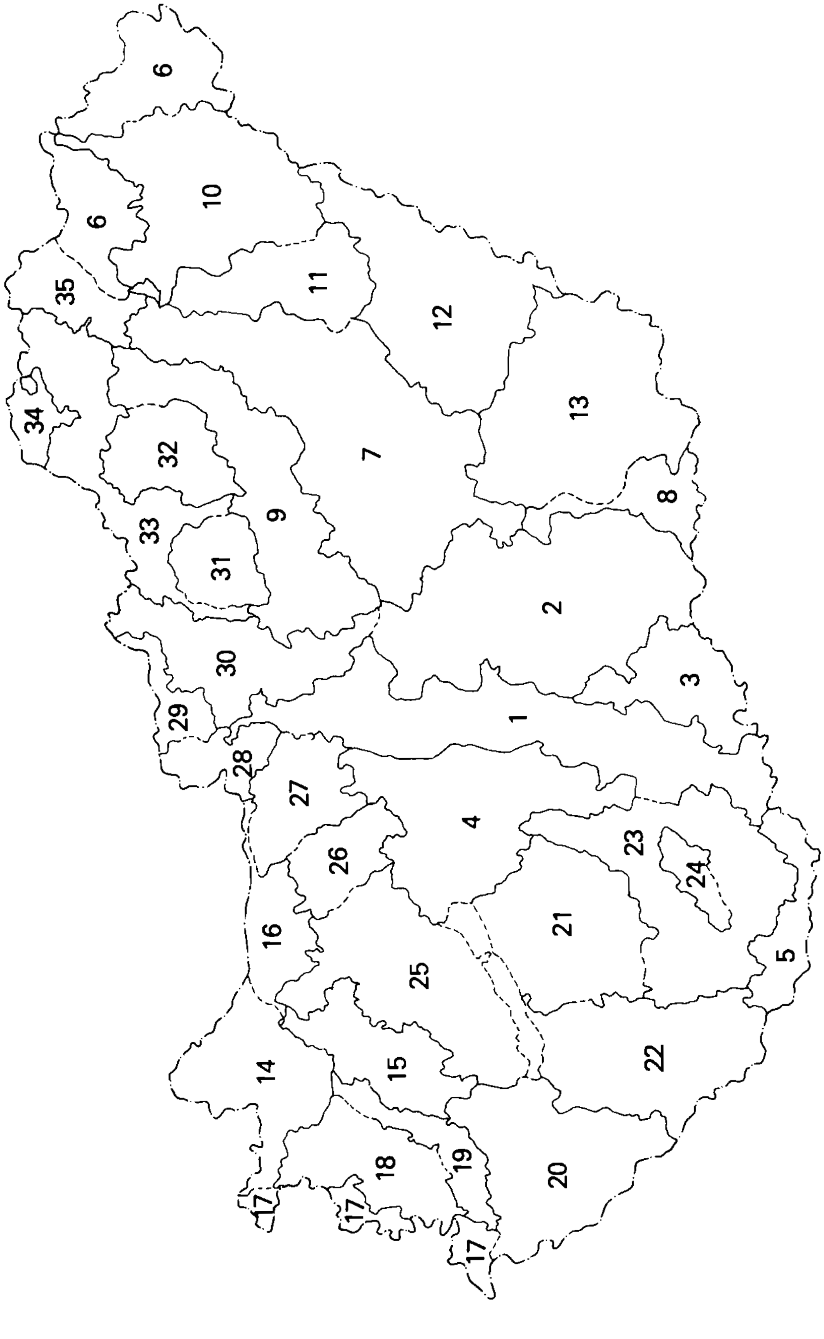


FIGURE 2 The ecological regions of Hungary.

To avoid this the country had to be divided into an ecological "mosaic", within each part of which production could be conducted under spatially homogeneous conditions. Homogeneity in time cannot be postulated owing to variable meteorological conditions but each unit of the mosaic is characterized by the same meteorological parameters.

Taking the foregoing definition into consideration the ecological mosaic was formed as follows. (1) 35 ecological regions were classified mainly on the basis of geographical and climatic conditions (Figure 2). The meteorological conditions within the various regions are considered as homogeneous. (2) The ecological regions were further divided according to soil types; in all, 31 soil types were differentiated.

In fact, the natural basic units are the soil regions formed in this way; these units are also characterized by the climatic conditions according to regions. The further division of the mosaic according to land use is also determined mainly by regional factors. A soil unit suitable for field crops cannot be a steep slope or a flooded area, have soil with too shallow a fertile layer, etc.

Using this classification the country was divided into about 300 units. The characteristics of these units are as follows: (1) they are geographically homogeneous areas; (2) their soil types are the same; (3) meteorologically they are homogeneous in space but vary over time; (4) their hydrological conditions depending on the climate are inhomogeneous with respect to time. Here the division was according to "physical" conditions.

The basic environmental conditions of the individual ecological units can be improved by, for example, irrigation.

In the second phase of the forecast preparation an assessment was made of the kind of improvements that were possible for the different ecological units and the degree to which these modified the forecast yield. The course of the forecast for the ecological units formed in the way described was the following: phase I, preparation of the forecast and collection and distribution of information material according to crops; phase II, written expert estimates and their evaluation; phase III, investigation of the possibilities of improvement and irrigation and estimation of their expected effects on the yield.

The forecast covered the following field crops: wheat, maize, alfalfa, sunflower, sugar beet, spring and winter barley, rye, fodder peas, red clover, rice, soybeans, and potatoes. For each crop expert groups of 10–20 members were formed. The members of the groups were selected from the foremost Hungarian specialists on each crop. In advance, the members of the groups received information packages which contained the most important soil, meteorological, hydrological, and plant-production data for the 35 regions and the given crop. The information packages also contained a summary describing the technical–technological conditions assumed for Hungary in the year 2000.

3 PHASE I

The forecast for each crop was prepared in the following stages: (i) determination of the conditions affecting the growing of the given crop and characterization of the regions on the basis of this; (ii) compilation of material connected with genetic development and description of the Hungarian situation; (iii) collection of yield data according to regions, analysis of yields, and preparation of international comparisons of cases; (iv) compilation of information packages from the data obtained from phases I and II, the drawing up of questionnaires, and their distribution to the members of the expert groups.

3.1 Stage (i)

(a) The regions in which the respective crops would be expected to be grown in 2000 were determined on the basis of the production conditions (soil, climate, hydrological conditions, etc.) for the various crops and their probable economic role. Henceforth the collection of data and the analysis were concentrated on these regions. In the case of some important crops (wheat, corn, alfalfa, etc.) every region was taken into consideration even if the yield averages attainable there were probably low; in other cases the study was restricted to the regions where production was expected to be "profitable" or the production of other crops seemed to be illogical.

(b) In Section 2 it was explained that the ecological mosaic was formed essentially on the basis of the soil types found in the different units. Because of the great number of soil types they were divided into categories according to crop suitability. Experts on plant production and soil science formed five or six categories of soil types according to crops, taking into account the conditions of production. For each region the categories (and within each category the soil types that could be found) and the percentage area that each soil type represented in the region were given. The regional estimates were prepared according to soil categories.

(c) The climatic year types were developed according to crops and the regions were characterized on this basis. With the help of agrometeorologists it was determined which meteorological parameters had the greatest effect on the yields of various crops. These parameters were obtained partly by statistical analysis (factor analysis, correlation analysis, etc.) of the yield results and the meteorological data for 25 years and partly by expert advice from agrometeorologists and plant-production specialists. The 25-year time series of the 2–6 parameters determined in this way according to species were divided into three or four categories per region using cluster analysis.

The data from a designated meteorological observation station in each region were taken as a basis. As an example we give the characterization of the climatic year types formed for sunflower. The following six parameters were taken as a basis: (1) heat units higher than 5°C in the summer half-year (April–September); (2) total sunshine hours in the summer half-year; (3) total precipitation in the summer half-year and October; (4) precipitation in September; (5) precipitation in October; (6) total precipitation in the winter half-year (October–March).

On the basis of processing data for the 25-year time series, four categories were classified using cluster analysis. The various types were characterized by the median of the categories and the frequencies of the years belonging to the categories were given as well. In order to demonstrate the differences according to regions the results for three regions are given in Table 1.

TABLE 1 Classification of regions by cluster analysis.

Climatic year type	Heat units above 5°C, April–September	Total sunshine hours, April–September	Total precipitation, April–October (mm)	Total precipitation, September (mm)	Total precipitation, October (mm)	Total precipitation winter half-year (mm)	Frequency (%)
Region 1							
A	2290	1430	260	30	200	180	20
B	2230	1290	330	30	50	260	28
C	2340	1450	250	30	35	210	48
D	2510	1500	270	125	50	380	4
Region 2							
A	2260	1450	300	25	25	220	48
B	2170	1290	380	40	110	160	8
C	2460	1600	200	70	48	200	20
D	2380	1600	270	15	20	300	24
Region 3							
A	1925	1470	330	35	20	280	32
B	2100	1400	380	35	80	220	32
C	2300	1560	200	100	40	210	16
D	2350	1560	290	15	15	360	16

3.2 Stage (ii)

The yields attainable in plant production and thus the preparation of the forecast is greatly affected by the development of the genetic potential and any increase in the proportion of full potential attainable in practice. Several materials were prepared to support the forecast in this way: the genetic potential of the given crop was estimated and a summarizing analytic study of the Hungarian situation and the expected changes in production was prepared.

The yield results for experimental plots and field trials on farms and farm-production data for the last 20–25 years were collected to show the changes. This material also allowed us to make a comparison of the results achieved in each of the three environments (see Figure 3).

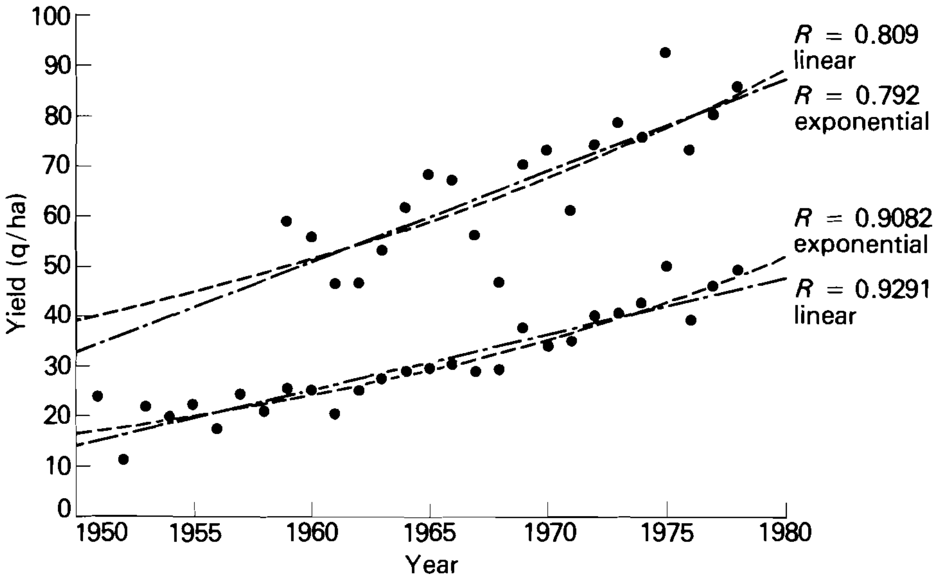


FIGURE 3 Maize yield averages in Hungary, national and experimental: national average, 2.97 t ha^{-1}; national increase, 0.11 t ha^{-1} $year^{-1}$; experimental-plot average, 6.61 t ha^{-1}; experimental-plot increase, 0.18 t ha^{-1} $year^{-1}$.

3.3 Stage (iii)

Several compilations were made to characterize developments in crop production (see Table 2 and Figures 4 and 5). In the case of a few crops an international comparison was also possible (Figure 6).

TABLE 2 An estimation sheet with climatic, soil, and yield information (for the Zala Hills region).

		Climatic year type			
		A	B	C	D
Soil category	I				
	II				
	III				
	IV				
	V				

Soil types

Category	Soil type number	Type	Frequency (%)
III	7	Clay leached brown forest soil	30
II	8	Pseudogleyed brown forest soil	30
IV	9	Brown forest soil	6
IV	26	Meadow alluvial soil	3
II	27	Meadow peat soil	4
I	28	Low-moor soil	6
III–IV	31	Alluvial soil	8
		Other	3

Climatic year types

Type	Precipitation (mm)	Heat units	Frequency (%)
A	270	1270	20
B	375	1500	24
C	750	1140	4
D	450	1270	52

Yield results

Year	Sowing area as percentage of the arable land	Average yield (q ha^{-1})
1951–1957	16.3	24.5
1972	17.9	33.4
1973	23.2	37.3
1974	23.0	36.1
1975	22.1	44.3
1976	19.1	36.4
1977	16.6	43.2

What is your estimation of the percentage of maize grown within the arable area in 2000?

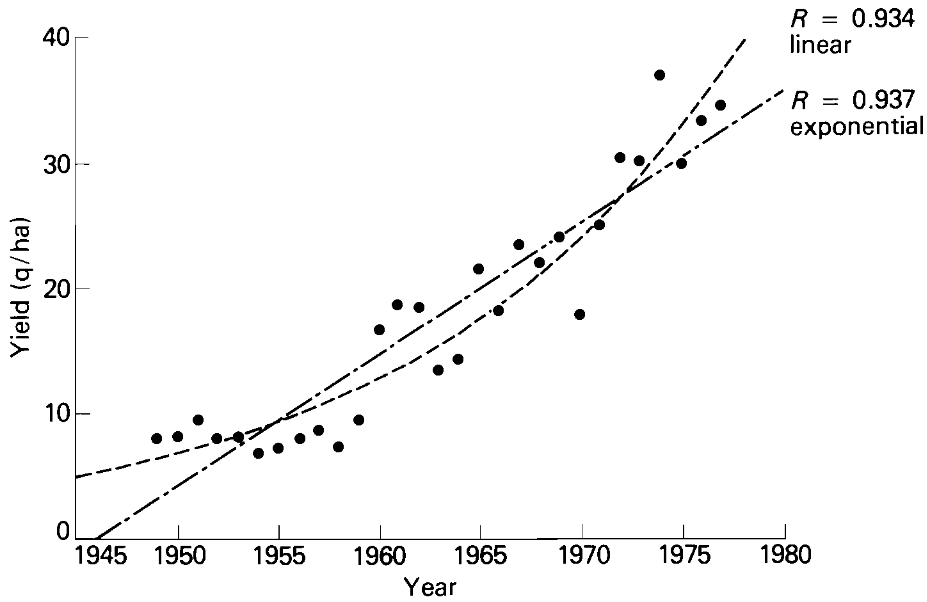


FIGURE 4 Wheat yield averages in Hungary.

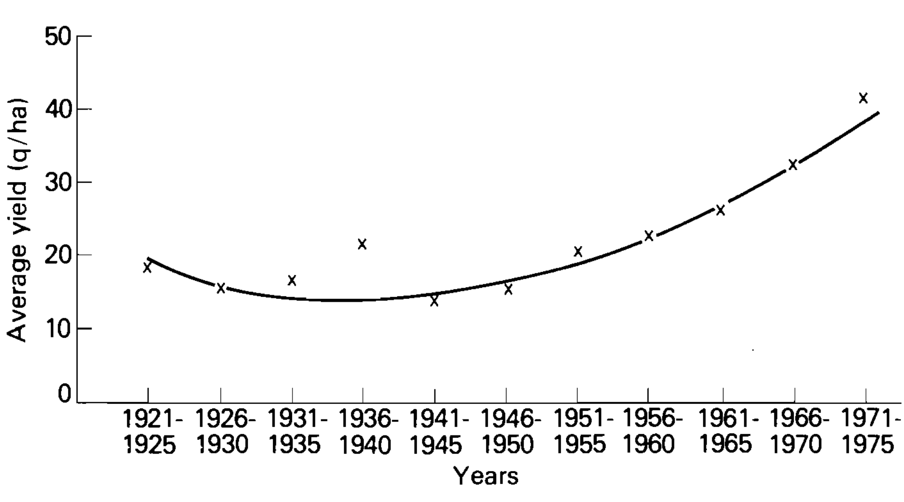


FIGURE 5 Maize yield averages in Hungary, 1921–1975. ($y = 21.92 - 3.58x + 0.47x^2$, $R = 0.965$.)

3.4 Stage (iv)

The so-called information package was prepared from the material presented with the aim of promoting the forecast. It also contained questionnaires, an example of which is shown in Table 2. The experts had to fill in the tables marked by columns A–D and

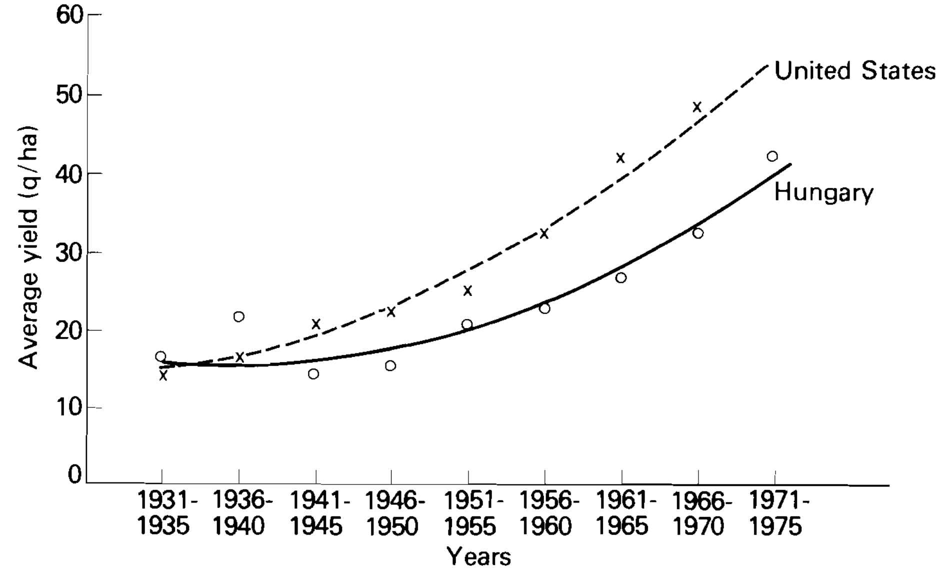


FIGURE 6 Maize yield averages in Hungary and the United States. (For the United States, $y = 13.58 + 0.59x + 0.44x^2$, $R = 0.985$; for Hungary, $y = 21.92 - 3.58x + 0.47x^2$, $R = 0.965$.)

rows I–V. A–D and I–V represent respectively climatic year types and soil categories, the exact descriptions of which can be found in Table 2.

4 PHASE II

The experts' estimations were evaluated in two stages: (i) the statistical processing of the estimation sheets; (ii) the evaluation of the results of the processing in an expert discussion and their collective modification where necessary.

4.1 Stage (i)

The statistical analysis consisted of determining the following data: (1) according to soil and climate categories, the mean of the estimates, the standard deviation of the estimates, and the minimum and maximum of the estimates; (2) the expected yield averages according to soil categories, taking into account the frequency of occurrence of the climatic year types; (3) the expected yield averages of each climatic year type according to soil distribution; (4) the expected yield averages of the region on the basis of soil distribution and the frequency of the climatic year types. The values obtained through the processing were compared with the present actual data calculated from regional and national yield data. The evaluation was supplied to the experts making the forecast.

4.2 Stage (ii)

The experts took part in collective discussion, the purpose of which was the evaluation of the material compiled and its possible modification. Several problems were discussed; e.g. Is the forecast value realistic compared to the present national yield averages and the available international data? Are the ecological differences between the regions realistically reflected in the predicted yield averages of the various regions? Do the values forecast for certain crops show a realistic proportion to each other? The values obtained as a result of the expert discussion were accepted as the final forecast and were then processed further.

5 PHASE III

The forecast described in Sections 3 and 4 was prepared on the assumption that the parameters characterizing present environmental conditions do not change. This can be accepted as a starting assumption but if we want to use the forecast for long-term regional and economic planning the following questions should be examined further. Of the environmental factors affecting plant production, which can be modified, and where and to what degree, and what are the yield-increasing effects of these modifications? The decision whether these improvements are economical or not should be made by the economic specialists and engineers.

Three types of improvement can be determined: (1) atmospheric improvement; (2) earth-surface improvement; (3) hydrological improvement.

(1) The aim of the atmospheric-improvement group was to determine what losses could be taken into account owing to the effect of atmospheric phenomena. The data that can be determined include the extent of drought and frost losses and the probability of the occurrence of such losses according to region, the possibilities of soil erosion caused by wind according to region, and the areas suffering from atmospheric pollution that damages agriculture.

(2) Earth-surface improvement in many cases cannot be separated from hydrological improvement; thus, with the exception of irrigation, these should be treated as a whole. The survey had two main aims: (a) to determine on which ecological units it is expedient to make improvements (here the forecast values were used for the calculations); (b) to consider complex improvement measures in each case. The survey included the following possible improvements: land arrangement, reclamation of sandy soils, reclamation of acid soils, reclamation of salt-affected soils, subsoiling, and soil conservation.

(3) The irrigation survey was also carried out for each ecological unit. Taking into account long-term irrigation considerations it was determined in which regions and on what soil types irrigation was expected to be used and by how much irrigation could increase the predicted yields.

Obviously the investigation was not completed with the determination of the data discussed here. The work will continue in two major directions.

(1) There will be determinations and analyses of agricultural structures meeting various expected social requirements and utilizing the existing ecological conditions. This

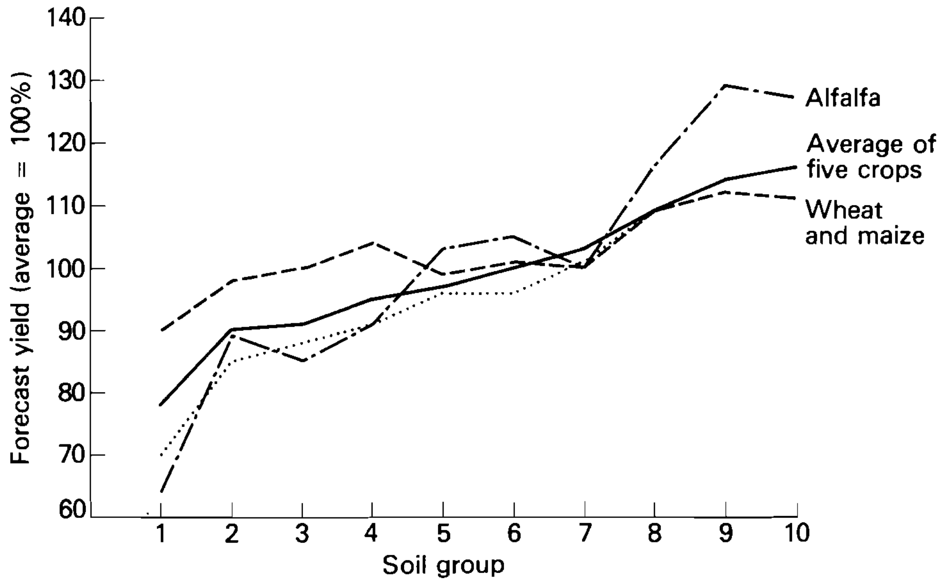


FIGURE 7 Evaluation of soils according to forecast crop yields.

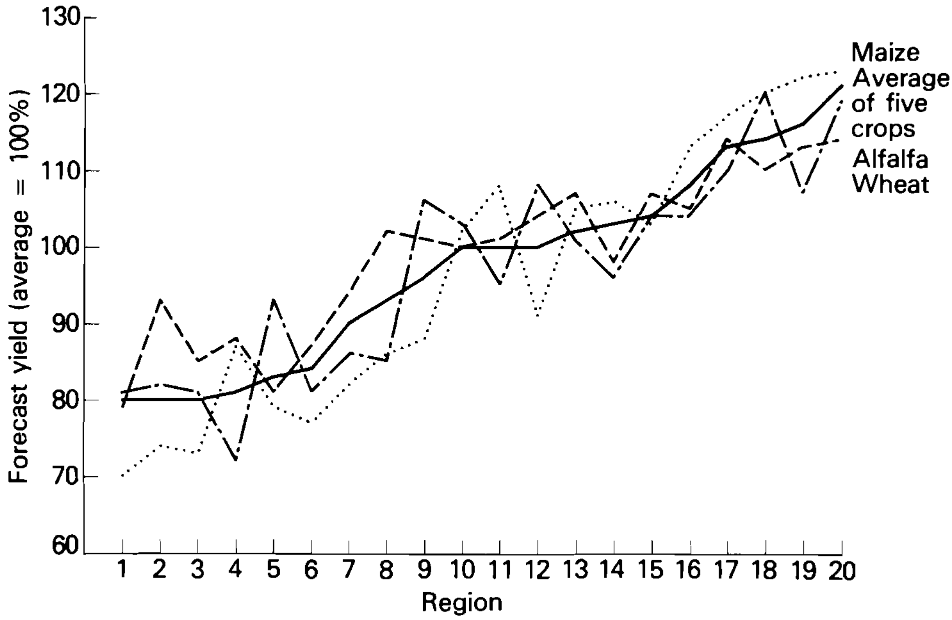


FIGURE 8 Evaluation of ecological regions according to forecast crop yields.

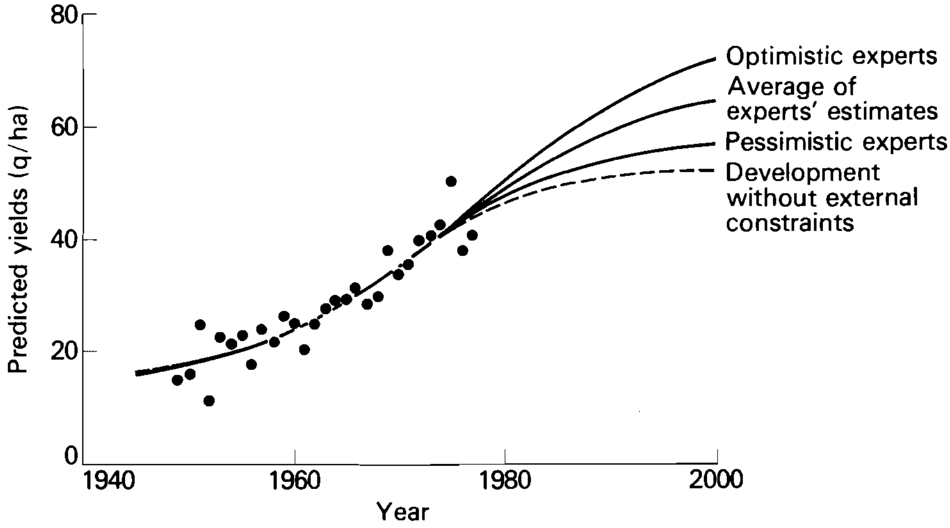


FIGURE 9 Predicted maize yields.

task will be stated as a multiobjective parametric linear programming problem which will then be solved as a compromise programming problem.

(2) Using the collected data and forecasts, studies will be made to explore the ecological reserves and the possibilities for their exploitation, to analyze the environmental production conditions found in each region or ecological unit, etc.

The characterization of the conditions existing in the regions and ecological units has started with the analysis of the predicted and existing yield results. The lowland areas and, within these, ten soil types were compared on the basis of the predicted yields of five arable crops (wheat, maize, sugar beet, sunflower, and alfalfa) (Figures 7–9). The expected yields of the various crops according to region and soil type were compared to the national average. Each region was characterized by the average of the values obtained in this way. The figures show how the qualification according to crops relates to the joint characterization and in which areas we can expect better or worse than average yields for the various crops.

DISCUSSION

In reply to a question by Driessen, Györffy *explained that the soil maps for every region give an evaluation of every soil type according to different crops. This allows a quantification of the yield potential by assigning in the model certain crops to certain particularly favorable soils.*

Robinson *stressed the difficulty that most statistical data are based on political units rather than on ecologically homogeneous zones.* Györffy *agreed that the first step consisted in breaking down existing data, sometimes even to units smaller than the village.* Robinson *wondered whether such an approach would be feasible for a large country (e.g.*

the United States) or for a global model. Győrffy *replied that this bottom-up approach is not limited to any one particular country.* Mula *reported that analogous work had just been started in Australia. Asked by* Mula *about the predictive value of the work,* Győrffy *replied that so far the work had been limited to replicating past trends.*

THE IMPACT OF SOIL CONDITIONS ON PRIMARY PRODUCTION

Paul M. Driessen
Centre for World Food Studies, c/o Agricultural University, P.O. Box 37, 6700 AA Wageningen (The Netherlands)

1 INTRODUCTION

Soils are the products of both destructive and synthetic forces that transform mineral rock and organic material into "natural bodies" that are (among other things) a habitat for plants. The complex soil–plant system, fed with energy from the sun, is our primary source of food. The effectiveness of this system as a producer of plant material is determined by crop characteristics and environmental factors, notably the availability of sòlar energy, water, air, and plant nutrients.

Solar energy is of paramount importance because higher plants convert inorganic substances to plant material on absorption of quanta of light (photosynthesis). Energy considerations set the ceiling on theoretical analyses of plant production if supplies of water and nutrients are assumed to be adequate. Soil conditions are not taken into account in classical calculations of the theoretical maximum dry-matter production of crops, although in practice the thermal properties of the soil may influence the rate at which synthesis of plant material proceeds.

Water is a major constituent of living plants. It is absorbed by the roots and is lost by transpiration through the stomatal cells. A very small proportion is used in photosynthesis or is retained in the plant where is acts as a solvent and carrier of nutrients and helps to maintain cell rigidity. If transpiration exceeds water absorption for any extended period, the plant loses water and wilts. It reacts by closing its stomatal openings, which prevents intake of carbon dioxide (an important raw material in photosynthesis) and causes reduced growth. The amount of water needed for unimpeded plant production depends on a number of factors such as environmental conditions, crop characteristics, and growth stage. The amount of water available to the plant is greatly influenced by the properties of the soil.

The importance of plant nutrients for crop production is obvious. Minerals are taken up from the soil solution in a dynamic process; any change in the concentration of one nutrient initiates a chain of reactions aimed at restoring equilibrium between minerals in solution and those associated with the solid phase of the soil. Nitrogen plays a special role in plant nutrition because of its behavior and mobility in the soil–plant system, the relatively large quantities needed by the plant, and the energy needed for the production of nitrogenous fertilizers.

The soil regulates to a considerable extent the supply of water and nutrients to the plant. This makes it an essential factor in primary-production models. The wide differences in physical and chemical properties between soils and the relevance of this for the production capacity of the land used require the close cooperation of crop-production specialists and land-evaluation experts in any attempt to assess the physical inputs associated with the production targets defined.

2 SOIL CONDITIONS AND PLANT PRODUCTION

Attempts to quantify the effects of soil properties on the soil–plant system meet with considerable difficulties. Soils are formed by the compounded effects of numerous physical, chemical, and biological processes, all with different intensities and durations. The wide variation in soil parent material, local erosion and transportation of soil material, and the increasing interference of man make soil genesis even more complex. Consequently soils often differ over only short distances. This hinders the characterization of a given area in terms of physical and chemical soil properties. Some degree of generalization of data is inevitable but it affects adversely the fit between measured production and its theoretical estimate. This inaccuracy of basic data (if data are available at all) and the lack of knowledge of the many interactive forces involved preclude the construction of anything other than very rough plant-production models. However, to disregard the impact of soil conditions altogether means to disregard processes that are fundamental to plant performance and this erodes the credibility of the entire modeling exercise.

2.1 Soil Conditions and Water Supply to the Plant

The water regime of a specific soil–plant system depends on a number of variables comprising both system characteristics and exogenous factors. The processes involved are conveniently described by a dynamic water balance:

$$I + N = ET_{re} + \Delta SM - LF - VF$$

in which (all quantities in cm)

I is the effective irrigation,
N is the effective precipitation,
ET_{re} is the actual evapotranspiration,
ΔSM is the net change in stored soil moisture,
LF is the net lateral influx of water, and
VF is the net vertical influx of water.

The balance expresses the system's tendency to strive for equilibrium between the influx of water and water losses, buffered by the varying amount of water stored in the soil. The situation is evaluated every ten days with the soil moisture tension ψ (expressed in bars or centimeters of water) as a monitoring tool. Feedbacks are taken into account by adjusting the parameters in successive iterations within each time interval. The following example may help to illustrate this.

A decrease in rainfall N in a certain area and period is often associated with a higher evaporative demand and with increased evapotranspiration ET_{re}. This prompts the plant to increase water uptake and causes a drop ΔSM in stored soil moisture, which is reflected by an increase in soil moisture tension. This change in turn is counteracted by increased influx of, for example, groundwater (VF). If, nonetheless, soil moisture stress reaches a critical value, specific to the soil–plant system under consideration, the plant reacts by reducing its consumption ET_{re}. A new state of equilibrium is then approached.

This simple example shows that a change in any of the parameters of the water balance affects the evapotranspiration term ET_{re} which is a measure of the intensity of plant metabolism and plant material production. Plant characteristics and soil properties together determine the elasticity of the soil–plant system. The lower boundary of the soil component is very important in this respect; it is set by the specific rooting properties and the growth stage of the crop if soils are homogeneous. Where discontinuities occur (e.g. hardpans or gravel banks at shallow depth) effective rooting depths are limited and hence consumptive water use and productivity of the crop are reduced. The physical limits to water-storage capacity and flow rates through the rooting zones are codetermined by the properties of the soil material. Soil is a porous medium; its total porosity and the pore size distribution determine how much water can be stored and with what force it is retained by the soil. This force equals the suction that the plant has to build up before it can extract moisture from the soil. The relation between the soil moisture content and the corresponding moisture tension differs between soils. Fine-grained soils such as clays have a relatively large component of fine pores that release water only if considerable suction is applied; in contrast, coarse-grained (sandy) soils have more wide pores that empty readily at low values of applied stress. In practice this means that sandy soils are often drought-sensitive while clayey soils hold more plant-available water. The latter soils, however, can have a low hydraulic conductivity associated with aeration problems during periods of wet weather. The intermediate-textured loams tend to combine good water-holding properties with sufficient aeration of the rooting medium and are productive soils with a high yield stability if fertilized.

2.2 Soil Conditions and Nutrient Supply to the Plant

The supply of nutrients to the plant depends not only on the quantity of nutrients contained in the soil–plant system or on the form in which these nutrients are present but also on the interactions between the various nutrients and on the system conditions that prevail. Plant nutrients are conveniently divided into the "macronutrients" (nitrogen, phosphorus, and potassium) and a large number of minor elements that are needed in comparatively small quantities.

As mentioned earlier, nitrogen is foremost in promoting vegetative plant growth and its availability governs to a considerable degree the need for other (so-called "mineral") nutrients. It occurs in soils as ammonium nitrogen (both in soluble form and fixed by clay minerals), as soluble nitrate, and as organic nitrogen tied up in humus compounds. The last form is largely unavailable to higher plants but is slowly released to plant-available inorganic forms on microbial breakdown of the organic structures.

The "nitrogen cycle" is greatly influenced by the characteristics of the soil–plant system, and particularly by soil properties. The quantity and quality of soil organic matter and clay (together with such composite factors as the soil–water regime, the soil–temperature regime, and the microbial activity) determine the amount of plant-available nitrogen, the amount of nitrogen fixed, and the amounts lost through leaching and volatilization.

Organic nitrogen constitutes the great bulk of all nitrogen present in the soil. Despite its slow rate of uptake by the plant it is the plant's main source of nitrogen unless commercial (inorganic) fertilizers are applied.

Mineral nutrients are also taken up by the plant from the soil solution. The solution acts as a "retailer" of plant food in that it holds a stock of readily available ions which is in balance with supplies from other sources such as dissociating mineral and organic soil material and ion-adsorbing surfaces of clay minerals and organic matter. The processes involved are complex; it suffices here to say that soil properties such as the clay content, the organic-matter content, the different surface-charge characteristics, the mineral assemblage, the water and temperature regimes, and many more determine the composition and concentration of mineral nutrients in the soil solution.

3 SOIL CONDITIONS IN THE CONDENSED PLANT-PRODUCTION MODEL OF THE CENTRE FOR WORLD FOOD STUDIES

The model outlined here is stripped of all but physical plant-production relationships. The importance of socioeconomic factors is properly taken into account in the full model but will not be discussed in this paper.

The condensed plant-production model as described here has a hierarchical structure. It starts from an estimation of the maximum dry-matter production that can be obtained under the prevailing energy conditions. A water balance is then drawn up on the basis of available climatic data, soil properties, and plant characteristics. For this purpose the soils of the area or region studied are grouped according to their textural composition. Some 20 texture classes have been defined, each with a standard set of soil properties. The soil properties include data on soil porosity, water-flow properties at defined moisture stress, water-content versus moisture-tension relationships, and material-specific constants. Solving the water-balance equation yields the so-called crop coefficient that is calculated for each interval distinguished within the total crop cycle. This coefficient describes the actual water consumption of the crop in question. The ratio between the calculated actual crop coefficient and the "maximum" coefficient of a closed well-watered standard crop in the same stage of development is indicative of the production that can be obtained under the prevailing water regime if all other production factors are assumed to be optimal:

$$\sum_{t=1}^{n} (P_{pot})_t = \sum_{t=1}^{n} [g(kc_{re}/kc_m)P_{st}]_t$$

in which

P_{pot} is the potential production at the prevailing water supply,
g is the crop coverage ($0 \leqslant g \leqslant 1.0$),
kc_{re} is the crop coefficient (from water balance),
kc_m is the maximum crop coefficient (tabulated), and
P_{st} is the absolute maximum dry-matter production (from energy considerations).

The ratio between straw and harvested produce is calculated by adding the $(P_{pot})_t$ for all intervals that occur prior to the flowering of the crop and dividing the sum by the sum of all dry-matter produced after that point. This vegetative–generative turnover point is a climate-dependent tabulated plant characteristic.

At the next-lower hierarchical level of the model the stipulation of optimal nutrient supply is lifted. Accounting for possible nutritional stress converts P_{pot} to P, the system's actual production of dry plant matter if losses through weeds, pests, diseases, etc., are assumed to be negligible. The model considers the nitrogen level of the system as an indicator of the overall nutrient status; this is a consequence of the assumption that the proportions of nutrients supplied are well balanced.

Figure 1 shows that the relationship between plant production P and nitrogen uptake N is linear for $P < P_{pot}$. The angle α, or dP/dN, follows from the water-balance equation that yields P_{pot} and the grain/straw ratio and from known representative nitrogen contents of grain and straw.

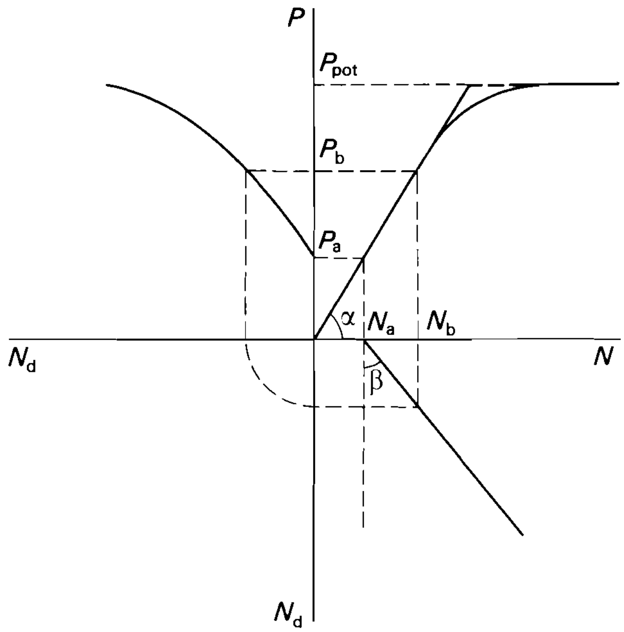


FIGURE 1 Schematic representation of the relation between nitrogen application N_d, nitrogen uptake N, and plant production P.

If the system's dry-matter production obtained without external inputs of nitrogen amounts to P_a kilograms of dry matter, the intersect N_a represents the "natural soil fertility" in terms of available nitrogen. This parameter can also be inferred from soil properties, notably from the content, composition, and decay rate of soil organic matter.

The relationship between the level of nitrogen application and the actual uptake of nitrogen by the crop is reflected by angle β. Including aftereffects in the stationary state, the recovery factor $\tan \beta$ varies in practice between 0.1 and 0.8 and depends heavily on soil conditions and the level of technology.

As simple goniometry shows, the fertilizer input required to produce P_b kilograms of dry matter amounts to

$$(N_d)_b = (P_b - P_a)/\tan \alpha \tan \beta$$

This relationship between nitrogen inputs and dry-matter production is expressed in the second quadrant in Figure 1.

The skeletal model structure described is supplemented with provisions for sub-optimal plant protection, weeding, harvesting techniques, etc. Thus a model is obtained that quantifies the water and fertilizer inputs required to meet a set production target under defined soil–plant system conditions.

4 POSTSCRIPT

The primary production model as it is currently being developed by the Production Group of the Centre for World Food Studies (CWFS) at Wageningen is an attempt to reach a long-standing goal of soil scientists, namely, an objective, reproducible, and quantitative method of appraising agricultural land in terms that economists and planners can use. Frequent and lengthy discussions with our colleagues in Amsterdam, who are in charge of the modeling of the socioeconomic aspects of food production, have shown that many of their questions are still unanswered. Therefore as a description of a production model this paper is premature. However, as an illustration of the importance of "the soil" for plant production we hope it serves its purpose.

ACKNOWLEDGMENTS

The text of this paper contains the ideas of the members of the CWFS Production Group: Messrs. Berkhout, Buringh, Driessen, Van Heemst, Van Keulen, Merkelijn, and De Wit. For the presentation of those ideas in this paper, however, the author is solely responsible.

DISCUSSION

Ayyad *raised the question of the ways in which this most interesting work could be applied to global modeling.* Driessen *answered that his work is independent of any* *socioeconomic considerations; plants behave according to certain laws of nature. The parameters in the equations may be influenced by socioeconomic factors but the equations themselves always hold. The model describes the amounts of input needed to arrive at certain production targets, so far for 13 types of crop. Asked by* Győrffy *about the salt balance,* Driessen *replied that, in Thailand for which the model was constructed, salinization plays no role. However, salt or other toxic substances (e.g. aluminum) could easily be introduced by reducing natural fertility and fertilizer recovery fraction.*

Parker *wondered about longer-term dynamic aspects: Is soil erosion considered?* Driessen *replied that erosion would enter into the model, as a spin-off from water-balance and nutrient considerations, not in the form of quantitative data but as an indication of those conditions under which erosion is liable to occur.*

Kellogg *asked whether the impact of possible changes in atmospheric carbon dioxide is taken into account.* Driessen *replied that it was not and added that this might represent a major problem: recent findings seem to prove that the amount of carbon dioxide produced by decomposing organic matter might be even greater than the amount introduced into the atmosphere by the burning of fossil fuels. In principle this could be incorporated into the model.*

AGRICULTURE, ECOLOGY, AND ENVIRONMENT AS A COMPLEX, INTERACTING, HIERARCHICAL CONTROL SYSTEM

K. Bellmann, E. Matthäus, K. Steinmüller, R. Straubel, and A. Sydow
Central Institute for Cybernetics and Information Processes, Academy of Sciences of the German Democratic Republic, DDR-1080 Berlin, Kurstrasse 33 (GDR)

1 INTRODUCTION

Because of the continuous growth of the various complex national economies natural limits to resources will be encountered in the future. Consequently the close interconnection of agricultural and environmental problems has become an important subject of both public and scientific research. On the one hand the industrialization of agriculture has an immense influence on the growth of agricultural production while on the other hand increasing production leads to the eutrophication and poisoning of rivers and lakes by the large-scale use of fertilizers and pesticides and to erosion by overgrazing. Thus agroecosystem productivity and regional ecological stability are conflicting key goals.

In this paper we present some considerations on methods of balancing these goals in a centrally planned national economic control system. Because of the complexity of the system we apply the well-known hierarchical concept from systems analysis (Mesarovic et al., 1970). The system that is investigated here is hierarchically structured in several ways.

(1) There is the natural functional hierarchy of the ecosystem.

(2) There is the spatial hierarchy of territorial administration. This hierarchy, with its national, regional, and farm levels, represents an economic subsystem of the whole national economic control system characterized by an overall performance function with regard to the national demands which have to be fulfilled by the national agricultural system in each year. This hierarchy of decision making, policy, and control (including a hierarchy of determination of the coordination variables for the lower levels and a hierarchy of the "measurement" of feedback information for the higher levels) corresponds to the different levels of national and regional administration.

(3) There is a temporal hierarchy both in the dynamic of the whole system and in the individual goals involved. At higher levels the plan for the development of the agricultural system is prepared for a long time horizon. The lowest level operates independently

only for a short horizon – below the so-called intervention time (Findeisen, 1977; Wismer, 1971).

Of course, all the types of hierarchy are intrinsically interwoven. In the following we elucidate some aspects of decision making for the interacting agriculture–environment–ecology control system.

2 ASPECTS OF THE SYSTEM ANALYSIS

2.1 The National Level

Disregarding supranational interdependences we can give a crude overview of factors on the national level which are relevant to agriculture–ecology–environment problems (see Figure 1). In Figure 1, R stands for natural resources with the output w (including ore deposits, energy sources, water supply, etc.). The water supply is, of course, often directly used in agriculture for irrigation purposes. I stands for industrial production with the output s. In the framework of this paper we are only interested in industry as the producer of fertilizers, pesticides, petrol, tools, machinery, buildings, etc., used for agricultural production. A stands for agricultural production (if necessary including the food industry). Fishing and forestry are ignored here. Agriculture receives resources, products of industry, and labor and is influenced by the weather M (i.e. climate), which is described by meteorological parameters m. We mainly consider the production of foodstuffs denoted by the yield y. H stands for the human population, which is affected by agriculture directly through food production and, mediated by the natural environment E, through pollution p. H includes the human labor supply l for agriculture and industry.

In the following we take into account only the aforementioned key processes (interactions) related to agriculture. The social value system, based on the nation's way of life, imposes certain population demands on, for example, the supply of foodstuffs and environmental quality. These demands may be expressed as restrictions on yield ($y_{\text{nat}}^{\text{min}}$) and pollution ($p_{\text{nat}}^{\text{max}}$) (both to be considered as real vectors). Any policy realized in the decision hierarchy has to take into account these constraints. The maximum acceptable pollution level $p_{\text{nat}}^{\text{max}}$ is to be calculated not only to guarantee a certain recreational quality for the environment but also to cut down negative feedback from the environment to industry and agriculture. In addition to these restrictions, the social system of values also implies a set of goals. Considering only agricultural goals we can formulate two of them: (1) agricultural-benefit maximization, $B(p, y) \to$ maximum, where B is a utility function of p and y; (2) agricultural-cost minimization, $C(y) \to$ minimum. Goal (2) is subject to the restriction $C \leqslant C_{\text{nat}}^{\text{max}}$, depending on industrial capacity, allocation of the gross national product, etc. The costs could also be written as a function of labor and capital (both agricultural and industrial) spent for agricultural production.

Up to now we have not considered the question of different time horizons. With a presumed time preference function $F(t)$ the step to long time horizons could be reduced to, for example,

$$\int_0^\infty F(t)B(p, y, t)\,\mathrm{d}t \to \text{maximum}$$

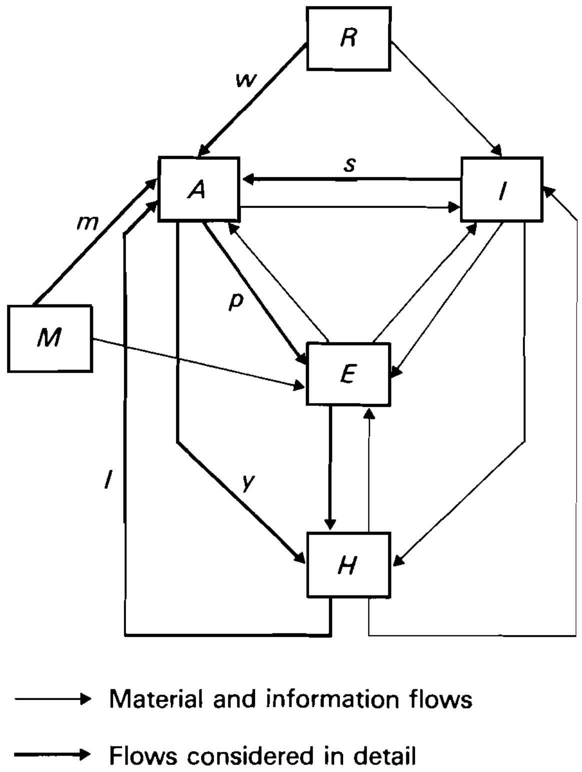


FIGURE 1 Some relevant interdependences of agriculture at the national level (the parameters are defined in the text).

But this is only part of the truth. One long-term goal is the restoration of the environmental quality of E (where necessary). This implies the goal

$$p(t) \xrightarrow{t \to \infty} p^{\text{opt}}$$

which can easily be reformulated as "the cost of obtaining 'optimal pollution' at time t" by means of appropriate goal functions which are increasing functions of time. It should be noted that in the long run all restrictions are functions of time.

As an example of agricultural production factors we consider the chemical substances s produced by industry I and used in the agricultural sector A as fertilizers and pesticides; at the least, the minimum yield $y_{\text{nat}}^{\text{min}}$ must be produced using $s_{\text{nat}}^{\text{max}}$. The supply of chemicals for agriculture is restricted by industrial capacity and import capabilities to a maximum value $s_{\text{nat}}^{\text{max}}$. Imports could also diminish the demand for agricultural yield $y_{\text{nat}}^{\text{min}}$. Of course home-produced fertilizers as well as imported fertilizers or foodstuffs should be taken into account in the cost function.

In our hierarchical approach we do not assign to each economic sector a certain production function (e.g. a function f_A for agriculture, which gives $y = f_A(l, w, s)$) as is usual in single-level modeling. We split up each sector of the national level into sectors on the regional level (e.g. regional agricultural sectors) embedded in regional ecosystems. After the establishment of regions, which in itself can be seen as a decision process (optimal regionalization), the decision problem at the national level consists in (1) finding optimal allocations of restrictions and resources for each region and (2) deriving regional goal functions. In more economic language, this should result in the optimal allocation of capital and labor to the regions and the optimization of interregional exchange. This means that one has to find the following for any region.

(1) A set of restrictions $y_i^{\min}, s_i^{\max}, p_i^{\max}, l_i^{\max}, C_i^{\max}, \ldots$, (where i is the region index) with aggregation conditions for the extensive variables

$$\sum_i y_i^{\min} = y_{\text{nat}}^{\min}, \qquad \sum_i s_i^{\max} = s_{\text{nat}}^{\max}, \qquad \sum_i C_i^{\max} = C_{\text{nat}}^{\max}$$

Since we consider the pollution density (i.e. p per unit area) no such equation holds for pollution.

(2) A set of available production factors s_i, with $\Sigma_i s_i = s$.

(3) A set of goals such that the overall national goals may be fulfilled. Thus the sum of the actual yields of the regions should equal the national yield: $\Sigma_i y_i = y$. The same should be true of costs: $\Sigma_i C_i = C$.

2.2 The Regional Level

Historically, agricultural regions have been distinguished by soil and climate types; this guarantees a certain homogeneity of the natural production conditions within a region (e.g. a district with sandy soil and high rainfall or a district with heavy soils and an arid climate). Determined by these natural conditions, each region has its special collection of optimal crop species (optimal implies high yield and low cultivation costs).

On the regional level the decision problem has much in common with the problem at the national decision level. Often even the goal functions are of the same type:

$$B_i(y_i, p_i) \rightarrow \text{maximum} \qquad C_i(y_i) \rightarrow \text{minimum}$$

For the allocations the following conditions hold:

$$\sum_j y_{ij}^{\min} = y_i^{\min}, \qquad \sum_j s_{ij}^{\max} = s_i^{\max}, \qquad \sum_j C_{ij}^{\max} = C_i^{\max}$$

$$\sum_j y_{ij} = y_i, \qquad \sum_j s_{ij} = s_i, \qquad \sum_j C_{ij} = C_i$$

where j is the farm index. All the remarks concerning nation-to-region allocation may be applied also to farm allocations. However, on the regional level the restrictions on the use of chemical substances are not only subject to economic considerations but also to ecological ones. $s_{ij}^{\max}$ is determined taking into account long-term ecological predictions (e.g. the future level of pollution in the region). To obtain these long-term predictions and insights into the behavior of the ecosystem under different policies it is necessary to develop an appropriate simulation model of ecosystems. This simulation model is named SONCHES (see the next paper (this volume, pp. 167–178) Section 2). SONCHES maps arbitrary ecosystem structures on the basis of so-called compartments. Natural and societal regional conditions should also be taken into account together with aspects of regional planning.

2.3 The Farm Level

Agricultural production takes place at the farm level. Figure 2 shows the various relevant inputs and outputs of the yield production process in a schematic way. The parameters of the yield production process are soil parameters and genetic parameters of crops and other species (weeds, pests) of the agroecosystem. The costs are a function of the input:

$$C_{ij} = C_{ij}(s_{ij}, l_{ij}, w_{ij}, \theta)$$

where w_{ij} stands for irrigation and θ stands for parameters of the function C_{ij}. For the farmer, the benefits are the yield output y_{ij}. Therefore the decision–control problem on the farm level results as

$$C_{ij} \rightarrow \text{minimum} \qquad y_{ij} \rightarrow \text{maximum}$$

subject to

$$C_{ij} \leqslant C_{ij}^{\max}, \qquad s_{ij} \leqslant s_{ij}^{\max}, \qquad l_{ij} \leqslant l_{ij}^{\max}, \qquad y_{ij} \geqslant y_{ij}^{\min}, \qquad p_{ij} \leqslant p_{ij}^{\max}$$

This is of course a polyoptimization–multiattribute decision problem. Its special complication lies in the uncertainty of the system dynamics, i.e. the influence of weather and pests (the weather has a very short prediction horizon unfortunately). The simulation system SONCHES (see the next paper (this volume, pp. 167–178)) being developed in our

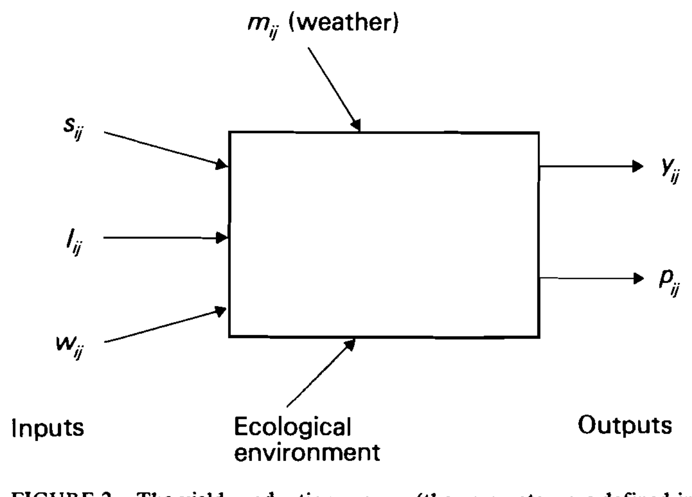


FIGURE 2 The yield production process (the parameters are defined in the text).

institute is capable of simulating the dynamics of almost any ecosystem, including agroecosystems. Given the control policy of the yield production process and the weather dynamics it predicts the annual dynamics of the agroecosystem and the yield. To overcome the problems of environment (weather) uncertainty methods of risk assessment may be applied, based on simulation studies. SONCHES can be used as a tool in the optimization of any agricultural–biological–environmental decision problem which involves ecological processes on the regional and the farm level.

There is another way to overcome environmental uncertainty: namely through industrialization of agriculture, which implies a reduction of environmental influences on the yield production process (e.g. the use of greenhouses). This method needs special investments which usually are not available at the farm level. However, they can be allocated at the regional level.

Even at the farm level long-term goals are of special importance. Quite generally, they may be subsumed under the overall goal of maintenance of ecosystem productivity. This implies, for example, the prevention of soil deterioration (soil pollution, erosion, etc.). Ecological considerations result in a second important long-term subgoal: the maintenance of an optimal composition and low level of pests. Concerning the pest composition of agroecosystems, the following observation should be made: unrestricted application of pesticides can almost completely exterminate various pest species native to the original ecosystem. As a consequence new pest species, naturally resistant or adapted to the chemicals usually applied, can be expected to immigrate into the vacant ecological niches.

Agroecosystems are forced systems in the physical sense. Only sensible and balanced application of pesticides (and other chemicals) maintains their "stability". The simulation system SONCHES can also be used for optimization of pest control. One of the fundamental strategies for pest control and maintenance of soil fertility is crop rotation, i.e. the selection of an optimal time sequence of annual agroecosystem structures. Sometimes it is possible to derive from long-term or medium-term (one-year) goals operational goals to be used for the calculation of operative controls. An example of such an operative goal is the optimal hydration of the plant as a physiological condition for maximal dry-matter production. The hydration can be controlled by irrigation.

In Figure 3 a goal tree relevant to agriculture is proposed. The long-term goals also relate to the regional and national levels whereas the short-term goals are realized only on the farm level. It should be noted that these goals are occasionally in conflict and that only some of the relevant goals and goal dependences can be given.

3 THE HIERARCHICAL CONTROL SYSTEM

Assuming that an optimal regionalization of the national agricultural system is known, a multilevel (hierarchical) control for the agriculture embedded as a subsystem inside the national economic control system has the following form, based on well-known multilevel optimization procedures.

As shown in Section 2.1, the highest (national) level has to maximize the utilization function (which means maximization of the effectiveness of agriculture) on the basis of an aggregated economic model of agriculture. The optimum is to be found with the

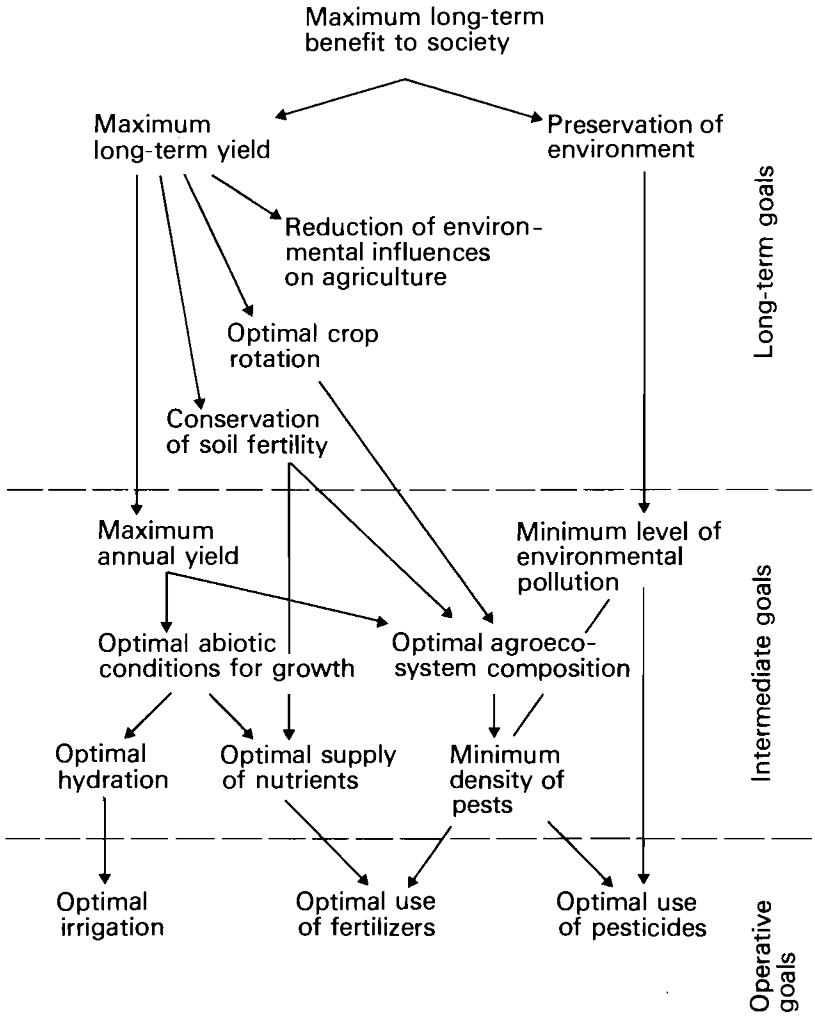


FIGURE 3 An agricultural goal tree.

various restrictions with regard to the maximum number of workers, investment, the use of industrial goods and resources, the maximum permissible deterioration of the environment, etc., being taken into account. (The time-dependent values of these restrictions are coordination variables of the economic control system of the whole nation.) The "off-line" optimization procedure is then realized for a long time horizon, assuming an annual average of the climatic conditions. The longer the horizon chosen, the better one can account for the natural course of development of the agroecological conditions. Of course the degree of uncertainty in future plans is increased by extending the horizon.

By this procedure the national level prepares annually the demands on the different subsystems at the regional level. Here the more operative optimization procedure is performed annually on the basis of a regional agroecological model with regard to agricultural

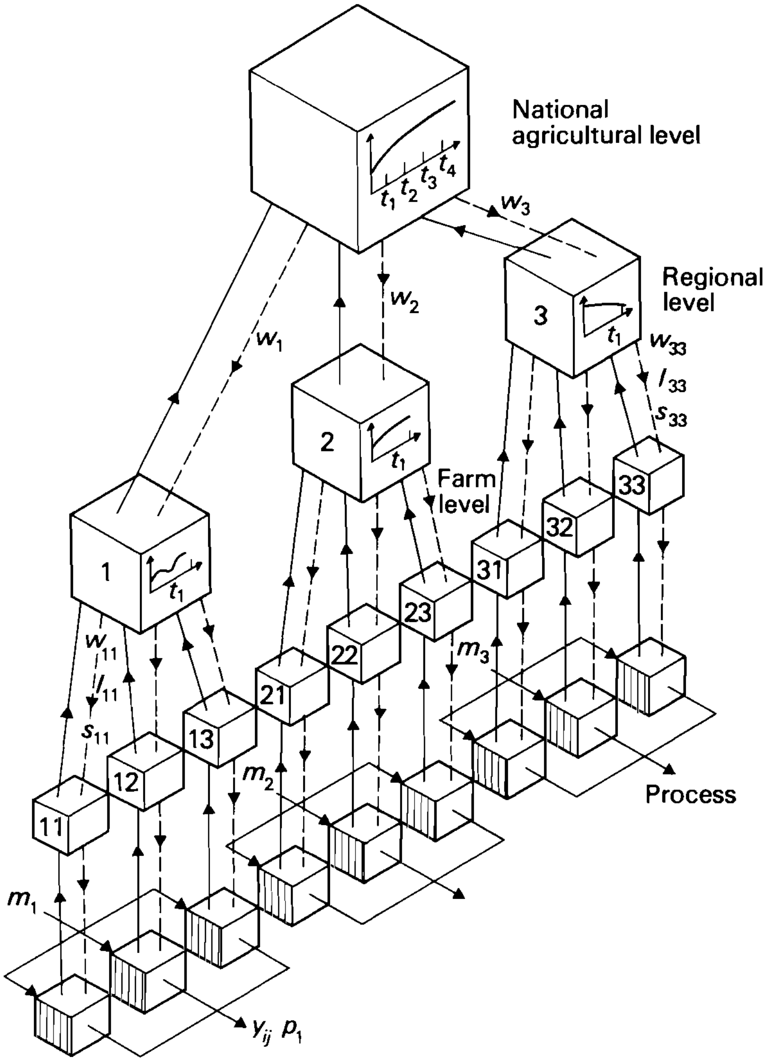


FIGURE 4 The hierarchical control system.

production and certain restrictions whereby the regional goal function is represented by the sum of the different goal functions of the farms at the lowest level. In this way the farm level can be coordinated by applying the so-called price method (Reinisch, 1977). Unfortunately at the regional level the restrictions are also influenced by other territorial long-horizon factors (e.g. settlement and migration). In this way the regional level is following the plan of the national level. However, in those cases where the demands of the national level cannot be fulfilled at the regional level a new optimization procedure must be realized at the national level on the basis of the feedback information from the regional subsystems representing the actual initial conditions for the computation.

The relations between the regional level and the farm level are analogous to the relations between the higher levels (see Figure 4). Thus the theoretical basis for treating such a complex control system by the multilevel approach already exists. The method of arranging such a control system would be to start with a simulation model such as SONCHES and derivative individual goal functions for the different farms. On the basis of these one has to find applicable, "measurable", sensitive coordination variables and feedback information so that at higher levels more and more individual parameters and variables characterizing the special models at each level can be aggregated. However, to realize these possibilities much system-analytic research has still be to done.

REFERENCES

Findeisen, W. (1977). Hierarchische Steuerungssysteme. Verlag Technik, Berlin.

Mesarovic, M.D., Macko, D., and Takahara, Y. (1970). Theory of Hierarchical, Multilevel Systems. Academic Press, New York.

Reinisch, K. (1977). Hierarchical control systems. Preprint of a paper presented at the IFAC Symposium on the Control Mechanism in Bio- and Eco-systems, Leipzig, 11–16 December, 1977.

Wismer, D.A. (Editor) (1971). Optimization Methods for Large-Scale Problems with Applications. McGraw-Hill, New York.

DISCUSSION

Driessen *asked whether "optimality" applied to production or to the minimizing of ecological stress.* Sydow *replied that both types of optima are being considered. The language used is rather flexible. A more detailed version of the paper was presented at the Sixth IIASA Global Modeling Conference in 1978.*

ECOSYSTEM MODELING AND SIMULATION: APPLICATION OF SONCHES TO AN AGROECOSYSTEM

K. Bellman, E. Matthäus, K. Steinmüller, R. Straubel, and A. Sydow
Central Institute for Cybernetics and Information Processes, Academy of Sciences of the German Democratic Republic, DDR-1080 Berlin, Kurstrasse 33 (GDR)

1 INTRODUCTION

The genuine importance of modeling, simulation, and systems analysis as bases for effective control in the field of ecology has been illustrated by many recent publications. Much work in promoting the dialogue on key issues in ecosystem modeling has been done by Holling et al. (1976), Patten (1971, 1973, 1975, 1976), van Dyne (1974), and others.

The success of ecological decision making based on models of large and complex ecological systems has raised hopes of solving the serious agricultural problems arising in the control of industrial crop production (Hampicke, 1977) by evaluating alternative policies from model simulations.

Ecosystems are complex, hierarchically structured, and nonlinear and dynamic in their behavior. Furthermore, successful control strategies for the management of agroecosystems can involve numerous factors, including stabilization of crop yield, pest control, tillage (i.e. use of fertilizer, irrigation, etc.), and control of soil fertility. Bearing in mind these system characteristics and the diversity of control strategies available, it is evident that the interdependent biological relationships of the system – some mutually reinforcing and some mutually opposed – can only be examined satisfactorily by building models of the system. Modeling offers possibilities for avoiding or reducing the damaging effects of agroecosystem management on parts of the system itself or on adjacent ecosystems.

In this paper we present an outline of our work on developing the SONCHES simulation system (Simulation Of a Nonlinear, Complex, Hierarchical, Ecological System) as applied to an agroecosystem containing the cultivated wheat *Triticum*, the fungal pest *Pseudocercosporella*, and the weed *Stellaria media*. Because of the lack of weed models, this study concentrates on modeling the annual development of *Stellaria media*.

Ecological modeling includes system analysis, model design, model validation and adaptation, and the testing of model sensitivity. The general objective for our work is the development of a representative (Innis, 1975) concept of the set of ecosystems. Thus a prerequisite has been a general formalized prototype of an ecosystem and of ecosystem elements.

All components of the investigated biological object having the same ecological function are lumped together in the same element (compartment) (Knijnenberg et al., 1980). We have chosen the algorithmic concept, including a deterministic, discrete-time, state-dependent description of the compartments, because one can find the best method of ecosystem mapping by progressively modifying the model structure. The algorithm model is partitioned into subdivisions for mapping the self-regulating mechanisms of compartments, controlling the environment-dependent behavior and the interactions between compartments, and controlling their abundance ratios and the interaction between the ecosystem and its environment. Each subdivision consists of modules containing the mathematical representation of one external interaction or of the intracompartment self-regulation mechanism. The interchangeability of modules makes allowance for the present incomplete but ever-increasing knowledge about valid general principles in ecology. Details are published elsewhere (Knijnenburg et al., 1981; Matthäus, 1978). The following description is meant to give some insight into the application of our modeling concept to a special agroecosystem whose main components are wheat, fungal pests, animal pests, and weeds. The results should be regarded as an interim report. This subject is still being elaborated by an integrated research group which includes scientists from various agricultural scientific centers.

2 STAGES OF AGROECOSYSTEM MODELING

Any agroecosystem can be divided into two subsystems of different complexity: (1) the above-ground community (biocenosis); (2) the biotic components of the soil. Modeling of the biocenosis is the easier task because of its low self-regulating capability as a consequence of the strongly reduced diversity of interactions and broken trophic chains.

With respect to the complexity of the system the following stages can be distinguished: (1) modeling of the growth processes of single objects without interactions (free-body case); (2) modeling of interacting objects; (3) modeling of complex soil processes; (4) modeling of the total agroecosystem. The first stage is essential for the whole modeling process (Caswell et al., 1972); we will therefore limit our detailed considerations here to free-body modeling and only sketch the second stage. The objective of modeling in this early stage is to establish those patterns of environmental factors which lead to optimal growth of cultivated plants, the increased prevalence of pests, or an increased proportion of weeds.

Two factors – one methodological and one prognostic – underline the importance of even this early modeling stage for practical applications. Firstly, the systematic application of the modeling concept to a specific agroecosystem requires the identification of all compartment parameters by experiments under definite conditions in a laboratory (i.e. completing our knowledge about all the objects in the biocenosis). Secondly, free-body model simulations based on environmental factors adjusted in various ways (including examination of the effect of parameter values that occur only rarely) allow prognoses to be made for specified "abnormal" conditions of weather (or irrigation).

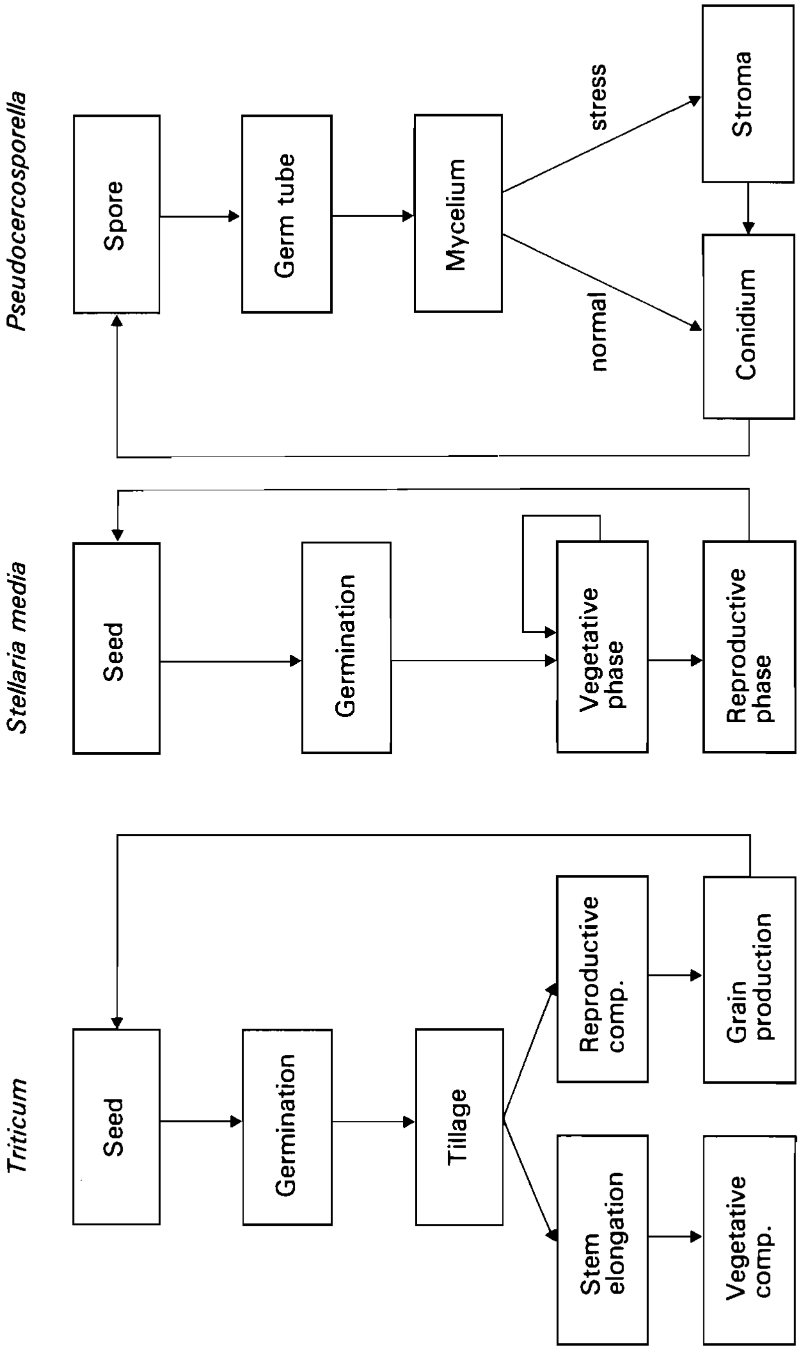


FIGURE 1 Compartment-succession graphs (diagram) of wheat (*Triticum*), weed (*Stellaria media*), and fungal pest (*Pseudocercosporella*).

2.1 Compartments of the First-Cut Model

The growth processes of biological objects (or species) are mapped by the compartment as a variable number of identical units characterized by a time-independent set of parameters containing lower and upper thresholds for environmental factors (input quantities) and intervals for the output performance (e.g. the number of seeds). If these parameters or the ecological interactions differ from the expected ontogenetic development, the growth process has to be divided into a sequence of compartments. Such compartment-succession graphs are displayed for the cultivated plant (*Triticum*), the main weed (*Stellaria media*), and the main fungal pest (*Pseudocercosporella*) in Figure 1. These three species are considered in the first-cut model for modeling complex pest effects.

2.2 Inputs

In this section the input variables essential for modeling plant–environment relationships are considered. The direct inputs from the environment are as follows:

x_1 is the incoming radiation energy ($J\,cm^{-2}$),
x_2 is the water available for use by the plants ($g\,cm^{-3}$) (soil model),
x_3 is the temperature (°C), and
x_{4_n} are the nutrients $(1, 2, \ldots, n)$ available for use by the plants ($g\,cm^{-3}$) (soil model).

The outputs of the wheat compartments, which are inputs for the fungal and animal pest compartments, are as follows:

x_{5_m} are the metabolic products $(1, 2, \ldots, m)$,
x_6 is the internal water content, and
x_7 is the biomass.

The outputs of plant compartments which modify environmental quantities (habitat control) are as follows:

x_8 is the extent of surface covering, and
x_9 is the leaf area index.

In the first and second stages, the dependence of the change of state of the wheat and weed compartments on water and nutrient supply can only be considered very approximately on the basis of hypotheses.

2.3 State Variables

For each compartment a pair of state variables $Z = (N, V)$ is used. The quantitative variable N describes the number of individual units (biomass, infested plant area, number

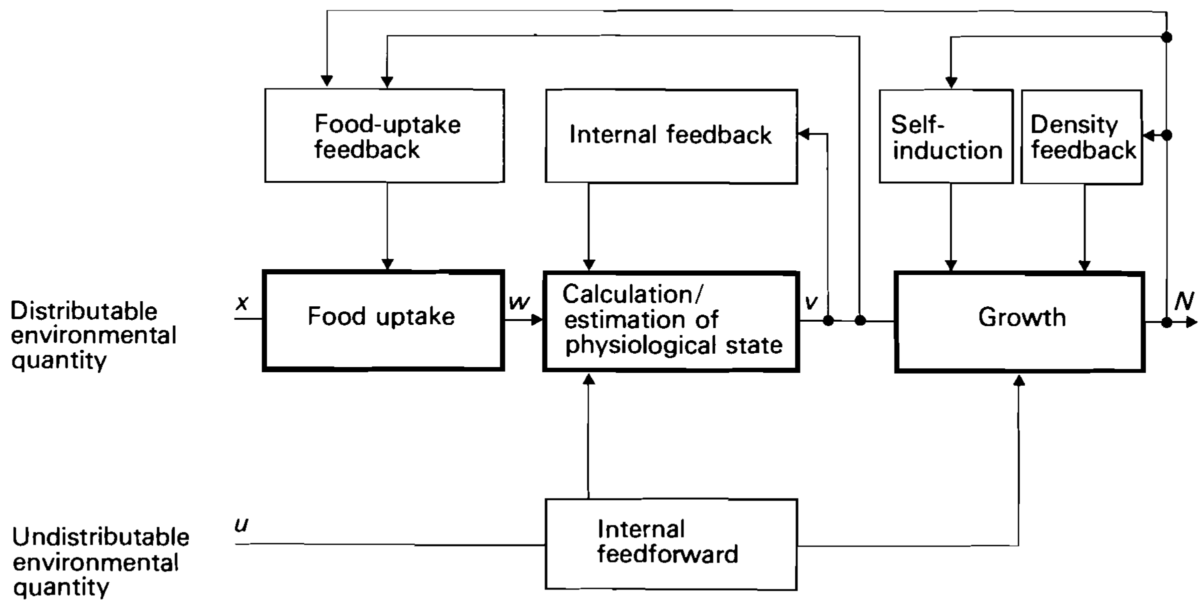


FIGURE 2 Block diagram of fundamental processes and the control mechanisms for modeling the free-body input–output behavior of compartments.

of larvae, etc.). The qualitative variable V describes the physiological state measured as supply state (storage capacity) or deviation from optimal conditions.

2.4 Fundamental Intracompartment Processes

In modeling the free-body input–output behavior of any given compartment the following three processes are considered (their interconnections are illustrated in a block diagram in Figure 2).

(i) The uptake of distributable environmental quantities:

$$w = f_1(x, d) \tag{1}$$

The fraction w of the environmental quantity x taken up is not only a function of x but also a function of state variables. This fact is taken into account in the demand d, which is calculated depending on N and V. (This is the food-uptake feedback for a donor-induced recipient-controlled process.) If the input quantities $x_1, x_2, \ldots, x_n$ do not vary independently of one another then the correlations between them have to be considered (input coupling).

(ii) The calculation of the physiological state:

$$V = f_2(w_1, w_2, \ldots, w_n, u_1, u_2, \ldots, u_k) \tag{2}$$

The modifying influence of undistributed quantities $u_1, u_2, \ldots, u_k$ (temperature, pH, etc.) on V as function of distributable quantities is separately considered in the internal "feed-forward". The internal feedback

$$V_t = f_3(V_{t-1}, w_1, w_2, \ldots, w_n, u_1, u_2, \ldots, u_k) \tag{3}$$

is used for modeling time-lagged first-order adaptation to environmental variations.

(iii) Growth/multiplication:

$$N_t = f_4(V_t, N_{t-1}, w_1, w_2, \ldots, w_n, u_1, u_2, \ldots, u_k) \tag{4}$$

The growth rate α_t is calculated at the individual level:

$$\alpha_t = g(V_t, w_1, w_2, \ldots, w_n, u_1, u_2, \ldots, u_k) \tag{5}$$

Growth at the compartment level is biomass induced (self-induction),

$$N_t' = \alpha_t N_{t-1}^{\kappa} \qquad \kappa = \text{induction parameter} \tag{6}$$

and density regulated (density feedback),

$$N_t = N_t' h(N_{t-1}) \qquad h(N_{t-1}) = \text{density function} \tag{7}$$

(cf. Getz, 1978). These mutually interdependent processes form the framework for the modeling procedure. Each functional response has to be identified for all compartments (see Section 3).

2.5 Interactions

Without going into details we list here the kinds of interactions which have to be considered, outlining the problems of the second modeling stage: (i) competition for energy, water, nutrients, and habitat within plant compartments; (ii) competence within plant compartments reflecting interferences caused by different degrees of adaptednesses (Steinmüller, 1980); (iii) competition within fungal and animal pest compartments for metabolic products and biomass; (iv) trophic interactions between plant and fungal pest compartments; (v) trophic interactions between plant and animal pest compartments. The interactions are schematically displayed in Figure 3; different ontogenetic compartments of the species are not distinguished.

3 GROWTH MODEL FOR THE VEGETATIVE COMPARTMENT OF *Stellaria media*

The vegetative compartment is the most important one with respect to the pest problem. Up to now no weed model has been available for modeling complex pest problems. Later on the model can be tested against experimental results and can be used for explaining observed irregularities in the normally rapidly-increasing plant mortality during the summer. As regards environmental quantities, the water available for plants measured as water capacity W (percentage water content) and the air temperature T (°C) have been considered explicitly. The remaining quantities have been assumed to be optimal and are not considered in the first-cut model.

3.1 Dynamics

The change of the state variable N (surface covering) is modeled (cf. eqns. 4–7) by

$$N_t = N_{t-1}[1 + \alpha^{\max}\alpha(V_t, T_t)]\, h(N_{t-1}) - \mu^{\max} H(T_t, W_t, V_t) \qquad (8)$$

where the time step is one week, and the other variables have the following meanings:

N is the extent of surface covering (%),
$\alpha^{\max}$ is the maximum growth rate per week ($0.9 \pm 0.1\%$ week^{-1}),
$\alpha(V, T)$ is the normalized growth rate (see below),
$h(N)$ is the density feedback ($h(N) = 1 - (N/100)^{\beta}$, and $\beta = 0.7 \pm 0.1$),
$\mu^{\max}$ is the estimated maximum mortality rate (0.5% week^{-1}), and
$H(T, W, V)$ is the step function:

$$H = \begin{cases} 0 & T_{min} \leqslant T \leqslant T_{max}, W_{min} \leqslant W \leqslant W_{max}, V > 0.01 \\ 1 & \text{otherwise} \end{cases}$$

where T_{min} and T_{max} are, respectively, the lower and upper values of the existence interval with respect to T ($T_{min} = 5\,°C$, $T_{opt} = 15\,°C$, $T_{max} = 35\,°C$), and W_{min} and W_{max} are, respectively, the lower and upper values of the existence interval with respect to W ($W_{min} = 10\%$, $W_{opt} = 70\%$, $W_{max} = 130\%$ (fictive value)).

We have restricted the maximum change of V per time step (internal feedback) to map a time-lagged and damped response to environmental changes.

$$V_t = \begin{cases} V_{t-1}^{\gamma^+} & V(W') > V^{\gamma^+} \quad \gamma^+ = 0.5 \\ V_{t-1}^{\gamma^-} & V(W') < V^{\gamma^-} \quad \gamma^- = 1.6 \\ V(W') & \text{otherwise} \end{cases} \tag{9}$$

W' is the water uptake W modified by the influence of temperature

$$W' = W/(1 + KT^{\nu})$$

where K and ν are free parameters which have to be adjusted for modeling the linear and nonlinear influence of T on water stress ($K = 1, \nu = 1$). The function $V(W)$ is assumed to be equal to the normalized growth rate $\alpha(W)$ measured in laboratory conditions where the water capacity of the soil has been kept fixed in each measurement and thus the physiological state has been adapted to the environment.

The growth rate $\alpha(W)$ and $\alpha(T)$ can be fitted by the same expression

$$\alpha(X) = \{\exp(-\rho\,[(X - X_{opt})/(X_{max} - X_{min})]^2) - \kappa\}/(1 - \kappa) \tag{10}$$

with

$$\kappa = \exp(-\rho[(X_{min} - X_{opt})/(X_{max} - X_{min})]^2) \quad \text{for } X < X_{opt}$$

$$\kappa = \exp(-\rho[(X_{max} - X_{opt})/(X_{max} - X_{min})]^2) \quad \text{for } X \geqslant X_{opt}$$

where X_{max} and X_{min} are, respectively, upper and lower values of the existence interval and X_{opt} is the value for optimal growth. The growth rate $\alpha(T)$ is asymmetric with respect to the optimal value described by $\rho(T < T_{opt}) = \frac{1}{2}\rho(T > T_{opt})$. Different combinations of $\alpha(T)$ and V have been used for $\alpha(T, V)$ where $\alpha(T, V) = [V\alpha(T)]^{1/2}$ fits best to map a time-delayed and damped response to environmental changes. The developments of water and temperature conditions were simulated by

$$T_t = -p_1 \cos t + p_2 + \sigma_1$$

and

$$W_t = -p_1 \cos 2t + q_2 \cos t + q_3 + \sigma_2 \tag{11}$$

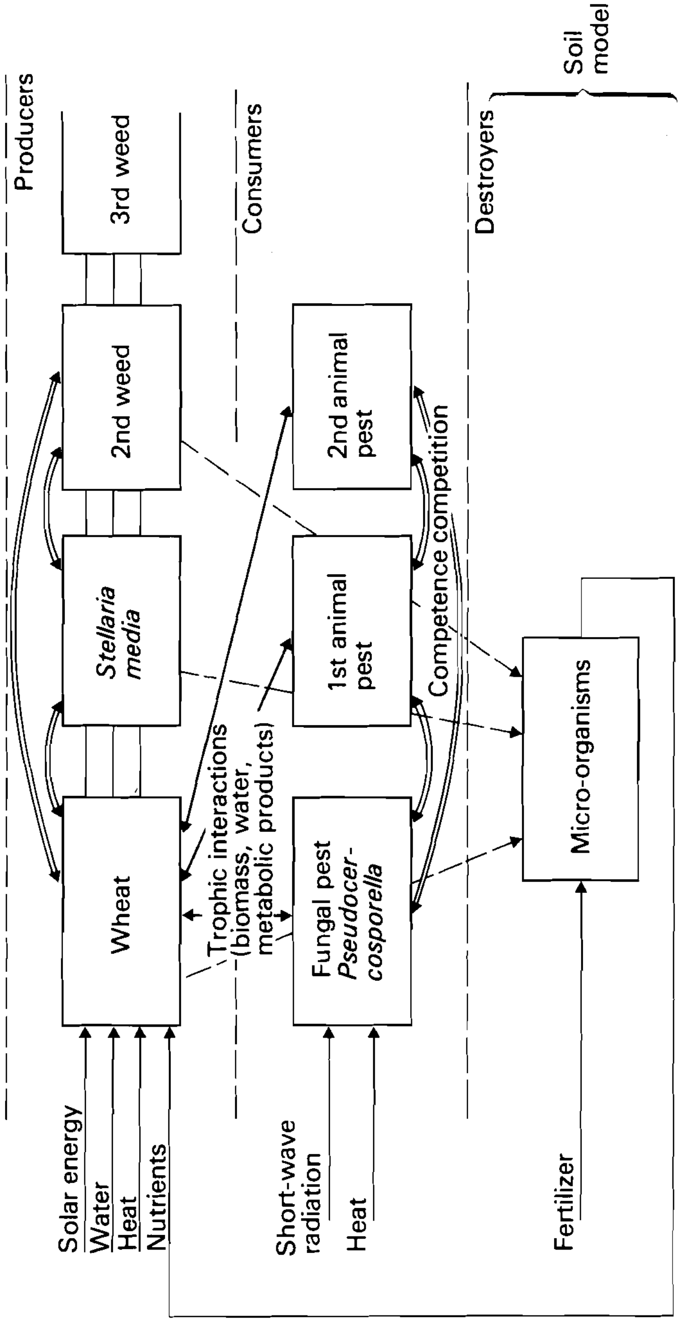


FIGURE 3 Schematic representation of interactions within the above-ground part of the agroecosystem composed of wheat, weeds, and animal and fungal pests.

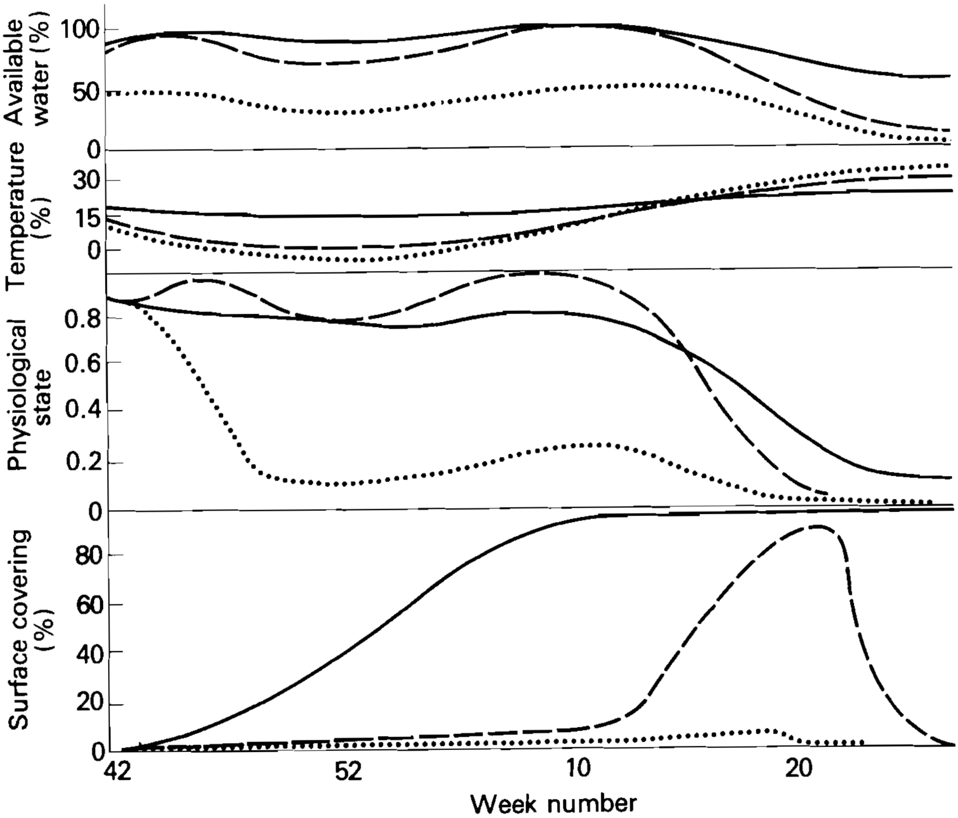


FIGURE 4 The annual development of *Stellaria media* for different climatic types: ——, maritime, $p_1 = 5\,°C, p_2 = 15\,°C, q_1 = 11.25\%, q_2 = 17.5\%, q_3 = 78.75\%$; — — —, temperate, $p_1 = 13\,°C$, $p_2 = 13\,°C, q_1 = 25\%, q_2 = 30\%, q_3 = 65\%$; · · · · ·, continental, $p_1 = 17.5\,°C, p_2 = 12.5\,°C, q_1 =$ $17.5\%, q_2 = 15\%, q_3 = 32.5\%$.

where p_1 and p_2 are temperature parameters ($p_1 = 13\,°C, p_2 = 13\,°C$), q_1, q_2, and q_3 are water parameters (water contents) ($q_1 = 25\%, q_2 = 30\%, q_3 = 65\%$), and σ_1 and σ_2 are evenly distributed random numbers within the given intervals ($-3\,°C, 3\,°C$) and ($-20\%, 20\%$), respectively, for stochastic simulations.

3.2 Discussion

All the parameters except p_1, p_2, q_1, q_2, and q_3 change the course of surface covering qualitatively but produce no breakdown which is dependent only on the environmental parameters. Different climatic types are generated by different parameter sets. The corresponding growth is shown in Figure 4. Here intuitive experience is confirmed; the best growth condition is the maritime climate. Using stochastic variants of the moderate climate, simulation results are compared with experimental data on the surface covering of *Stellaria media* in the years 1974–1977 (Figure 5). Periods of two or three

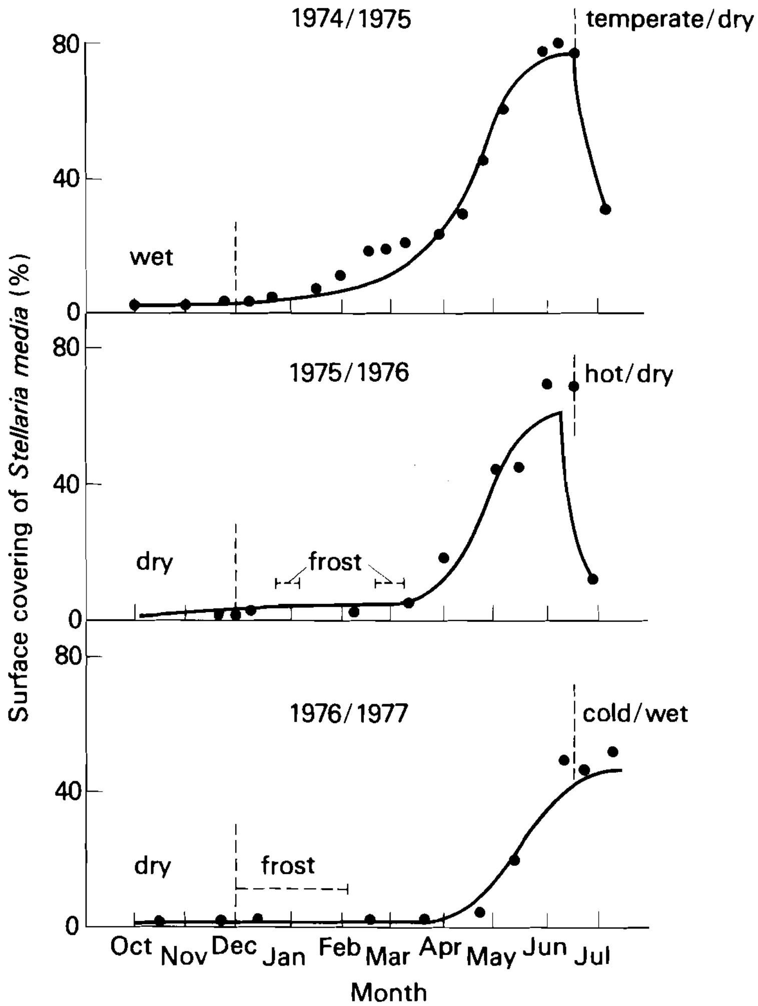


FIGURE 5 The development of the normalized surface covering of the weed *Stellaria media* for the years 1974–1977 (•) compared with simulation results (—) for three different weather situations during the period. (The data were obtained from experiments of the Institute of Plant Protection Research of the GDR Academy of Agricultural Science.)

months during the three years were classified as wet, moist, dry, cold, temperate, or warm according to the total precipitation and the mean temperatures within the periods. Those stochastic scenarios of the simulation results were chosen which correspond to the previously classified weather patterns. The calculated results coincide well with the experimental data.

Although the estimation of soil water by classification of precipitation was very inaccurate the calculated results coincide well with the experimental data without further model adaptation. The observation that the normal summer mortality of the weed was absent in 1977 could be reproduced by the model and explained by the maritime-like climate experienced during the summer of that year.

4 CONCLUDING REMARKS

In this paper only a few problems of modeling agroecosystems could be described. It has been shown that our modeling procedure is guided by a total ecosystem concept which will be further developed by considering ecological control mechanisms on higher decision levels of self-adaptation and self-organization. In most cases there is no real chance of a global adaptation of the model behavior because the responses of the modeled subject to definite input vectors take too much time or cannot be modeled for other reasons. Thus the decomposition of complex ecosystems into subsystems (performed by hand for the modeled agroecosubsystem with stepwise increases in complexity) and the separate validation and adaptation of the corresponding sections seem to remain the only technique. A model for the smallest possible subsystem (the free-body-case/one-compartment model) was qualitatively compared with field data; this showed a useful application of the ecosystem concept in explaining observed irregularities in the annual development of the weed *Stellaria media*.

REFERENCES

Caswell, H., Koenig, H.E., Resh, J.A., and Ross, Q.E. (1972). An introduction to systems science for ecologists. In B.C. Patten (Editor), Systems Analysis and Simulation in Ecology, Vol. 2. Academic Press, New York, pp. 3–78.

van Dyne, G.M. (1974). A systems approach to grasslands. In D. Daetz and R.H. Pantell (Editors), Environmental Modeling: Analysis and Management. Benchmark Papers in Electrical Engineering and Computer Science 6. Dowden Huchison and Ross, Stroudsburg, Pennsylvania, pp. 89–101.

Getz, W.M. (1978). On modeling temporal patterns in stressed ecosystems – recreation in a coniferous forest. Ecological Modeling, 5: 237–257.

Hampicke, U. (1977). Landwirtschaft und Umwelt (Agriculture and Environment). Dissertation, D 83, Nr. 24. Technische Universität Berlin.

Holling, C.S., Jones, D.D., and Clark, W.C. (1976). Ecological Policy Design: Lessons from a Study of Forest/Pest Management. University of British Columbia, Vancouver.

Innis, G.S. (1975). Role of total systems models in the grassland biome study. In B.C. Patten (Editor), Systems Analysis and Simulation in Ecology, Vol. 3. Academic Press, New York, p. 17.

Knijnenburg, A., Matthäus, E., and Stöcker, G. (1980). Zur Begriffsbestimmung des ökologischen Compartments – eine Grundkonzeption zur Ökosystemanalyse (On the Definition of the Notion "Ecological Compartment" – a Fundamental Concept for Ecosystem Analysis). Flora, 170: 484–497.

Knijnenburg, A., Matthäus, E., Lattke, H., Eggert, H., and Kalmus, A. (1981). Diskrete Simulation von ökologischen Regelmechanismen und ihre Anwendung am Beispiel eines Grobmodells der vegetativen Entwicklung von *Stellaria media* (Discrete simulation of ecological control mechanisms and their application to a model of the vegetative development of *Stellaria media*). In K. Unger and G. Stöcker (Editors), Biophysikalische Ökologie und Ökosystemforschung. Akademie-Verlag, Berlin, pp. 275–308.

Matthäus, E. (1978). Investigations of ecosystems by means of simulation. In Proceedings of the Conference on Mathematical Modeling of the Biogeocenotic Process, Puscino, USSR. (In Russian.)

Patten, B.C. (Editor) (1971, 1973, 1975, 1976). Systems Analysis and Simulation in Ecology, Vols. 1–4. Academic Press, New York.

Steinmüller, K.-H. (1980). Model considerations on niche overlap and interaction. Biometrical Journal, 22: 211–228.

A GLOBAL MODELING APPROACH TO THE MODELING OF WORLD FOREST PRODUCTS: A ONE-SECTOR GLOBAL MODEL

Rumen Dobrinsky
International Institute for Applied Systems Analysis, Laxenburg (Austria)

1 INTRODUCTION

Since the publication of "World Dynamics" (1971) and "The Limits to Growth" (1972) the scientific trend which has come to be known as "global modeling" has passed through several stages of development. The broad response to the pioneer works of Forrester and Meadows from both scientific circles and the general public provoked a long-lasting interest in the field of global modeling. The models that were created in the following years had different aims, were based on different approaches, and varied in the results and conclusions at which they arrived. However, on one point all global modelers were unanimous, and this was a starting point of all studies: because of the enormous complexity and the universal interrelationship of the global system nowadays, one must take into consideration as many as possible, if not all, of the aspects of the global system in order to obtain a true picture of its future development.

In the last few years the excitement about global modeling seems to have calmed down somewhat as it has become accepted as just one of the various scientific fields today. Nevertheless, more and more scientists with different academic backgrounds are becoming involved in global modeling activities, thus broadening the aims and scope of research (Richardson, 1978). The global modeling approach itself has been accepted and has been found to be extremely helpful in economic forecasting and planning (Panov, 1978; Panov and Dobrinsky, 1979), in ecological research (Moiseev, 1977), and many other areas.

The study of particular world problems by global modelers has resulted in the creation of one-sector global models such as the Model of International Relations in Agriculture (MOIRA) (de Hoogh et al., 1975), dealing with food production and the problems of malnutrition, and the world energy models developed at the International Institute for Applied Systems Analysis (Häfele and Basile, 1979).

In this study we attempt to apply the global modeling approach to the modeling of some forest products. The purpose of the study is to gain insight into the prospects for production and consumption of these products in the world as well as to assess the future trade flows and price trends. Another application of the model will be its linking with a national model of the forestry sector for the needs of the long-term planning of this sector of the national economy.

2 BASIC PROPOSITIONS OF THE MODEL

Forest products play an important part in human life. Despite progress in chemistry and the invention of various synthetics, wood is still the main raw material for the production of many industrial goods (paper products, furniture, etc.).

The demand for forest products is growing rapidly at present owing to the rapid growth of the world population and the high rates of economic development in most countries of the world in the postwar period. However, the natural resources – the forests – are limited; they are renewable, but only with considerable time delays. A recent study (Persson, 1974, 1977) of world forest resources showed that the total amount of closed forest in the world is about 2,640 million hectares with a standing volume of around 300,000 million cubic meters (see Table 1).

TABLE 1 World forest resources.

Region	Closed forest ($\times 10^6$ ha)	Standing volume ($\times 10^6$ m^3)
Africa	190	43,000
North America	450	41,000
Latin America	680	82,000
Asia	410	34,000
Europe	138	14,612
Oceania	89	5,000
USSR	680	84,000
World total	2,640	300,000

Another important point is that forests not only are a natural resource but also have a significant environmental impact. Many examples are known where rash deforestation has caused severe damage to the environment and even to the climate. This sets a further limitation on the volume of roundwood that can be produced on a global scale.

In the 1970s the world's total production of roundwood has almost reached the maximum possible, while per capita production is actually decreasing (see Figure 1). There are already some signs that the growing demand for forest products exceeds the supply and this has caused (together with the overall price increase of natural resources after the oil crisis in 1973–1974) significant increases in their prices on the world market. Figure 2 shows the price trends of roundwood, pulp, and paper products in the 1970s (the relative prices are estimated with respect to the world overall price index – the deflator of the world's gross product).

In this study we try to investigate future trends in the production and trade of some forest products using a global modeling approach. Up till now we have focused mainly on

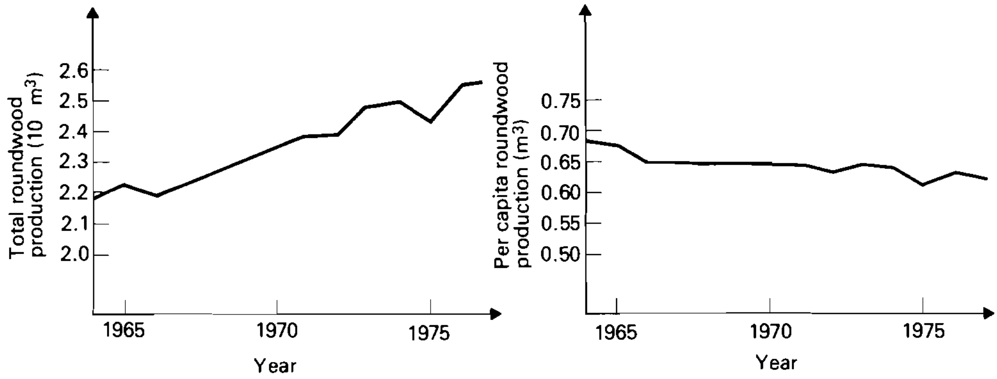


FIGURE 1 Total world and per capita roundwood production.

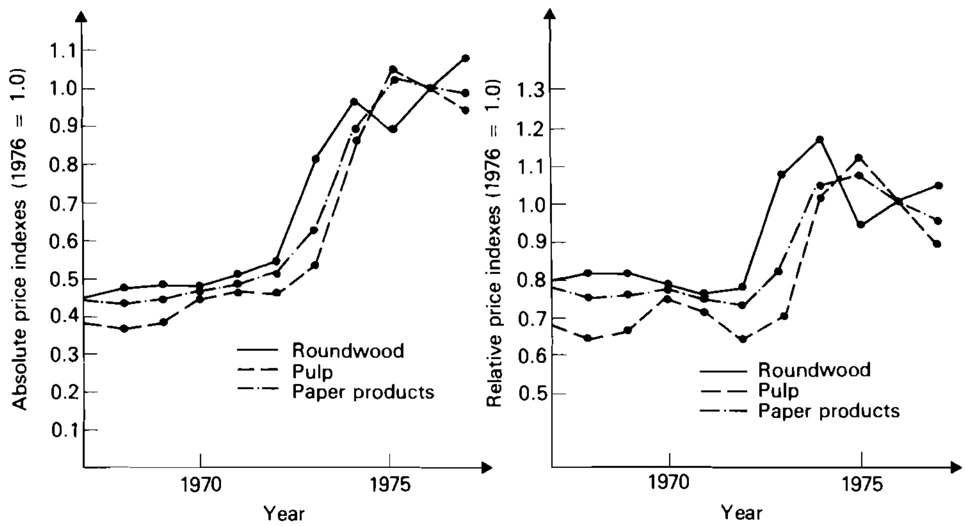


FIGURE 2 Absolute and relative price indexes of roundwood, pulp, and paper products.

products which result from the chemical processing of wood (e.g. pulp and paper products) but the scope can easily be broadened to take into consideration other forest products as well.

3 REGIONALIZATION

Regionalization is an approach used in almost all global models. It is an attempt to satisfy the conflicting requirements for accuracy of the model on the one hand and reasonable size and complexity on the other.

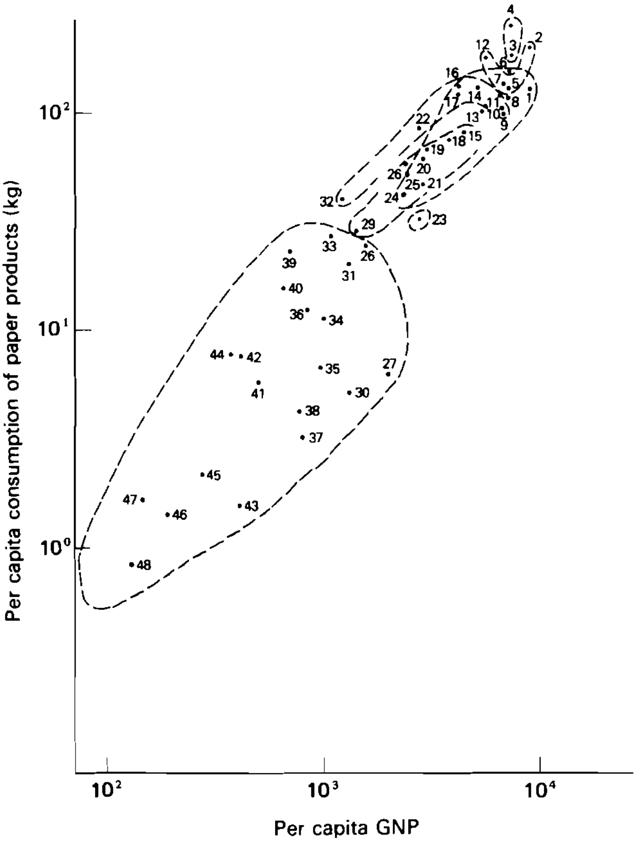


FIGURE 3 Per capita consumption of paper products in 1976 (the numbers correspond to the countries given in the regionalization in Table 2).

Statistical analysis of the patterns of production and consumption of pulp and paper products in the different countries of the world shows a strong correlation with the level of economic development. This correlation served as a basis both for the mathematical modeling and for the regionalization of the model. Figure 3 depicts per capita consumption of paper products in 48 countries versus per capita Gross National Product (GNP) in 1976; the corresponding regionalization adopted in the model is shown in Table 2.

In the present study the world is divided into seven regions as follows: (1) the Union of Soviet Socialist Republics (USSR); (2) Eastern Europe; (3) Western Europe; (4) Scandinavia; (5) North America; (6) other developed countries; (7) developing countries. This regionalization to a considerable extent coincides with the one accepted by the United Nations and the Food and Agricultural Organization and this made it possible to use material from the UN and FAO statistical yearbooks as the main sources of data for the model. Scandinavia was specified as a separate region since it is a major supplier of forest products. This system of regional division takes into account the different levels

TABLE 2 The regions used in the model.

Region 1	*Region 4*	*Region 7*
23 USSR	2 Sweden	27 Iran
	5 Norway	28 Argentina
Region 2	12 Finland	30 Iraq
15 German Democratic Republic		31 Brazil
18 Czechoslovakia	*Region 5*	33 Mexico
21 Poland	3 Canada	34 Turkey
25 Bulgaria	4 United States	35 Algeria
26 Hungary		36 Peru
27 Rumania	*Region 6*	37 Syria
	9 Australia	38 Tunisia
Region 3	14 Japan	39 Equador
1 Switzerland	16 New Zealand	40 Columbia
6 Denmark	22 Israel	41 Morocco
7 Federal Republic of Germany	32 South Africa	42 Philippines
8 Belgium		43 Nigeria
10 France		44 China
11 Netherlands		45 Indonesia
13 Austria		46 Pakistan
17 United Kingdom		47 India
19 Italy		48 Zaire
20 Spain		
24 Greece		

of economic development, the specific patterns and traditions in the production and consumption of pulp and paper products, as well as the forest resources of the various regions (see Table 3).

TABLE 3 Levels of natural resources, per capita production, per capita consumption, and production potential for wood and wood products in the regions.

Region[a]	Natural resources	Per capital production	Per capita consumption	Production potential
1	High	Moderate	Moderate	High
2	Moderate	Moderate	Moderate	Moderate–high
3	Low	Moderate–high	Moderate–high	Moderate–high
4	High	High	High	High
5	High	High	High	High
6	Low–moderate	Moderate–high	High	Moderate–high
7	Low	Low	Low	Low–moderate

[a] The regions are defined in Table 2.

4 QUANTITATIVE ESTIMATIONS AND MODEL STRUCTURE

The model is based on econometric relationships connecting production and demand for pulp and paper products with factors describing the general level of economic development (e.g. the Gross Regional Product (GRP) per capita in the different regions),

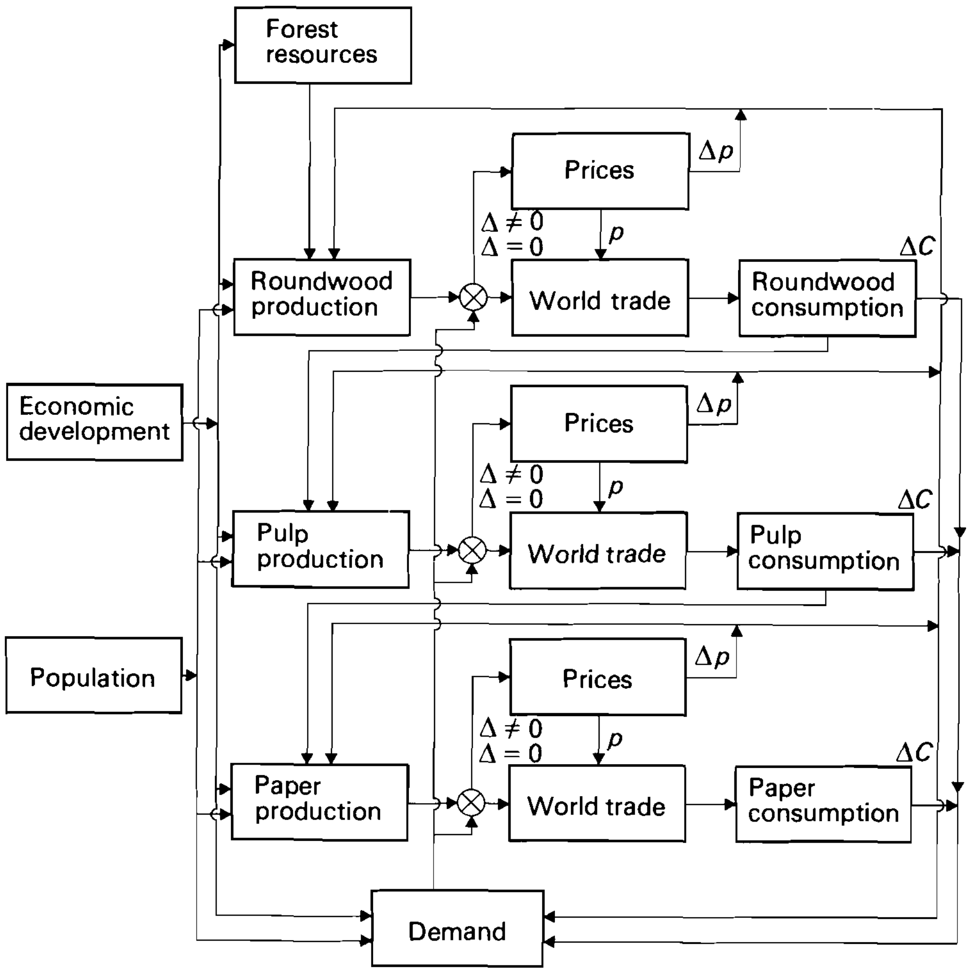


FIGURE 4 The logical structure of the model.

the availability of natural resources, traditions in this branch of industry, international prices, etc. Linear multiple-regression equations are used in most cases, and all the estimations are performed on a per capita basis.

The following is an example of an equation used in the model:

$$PLP_i^t = f(GRP_i^t, PLPB_i^t, RWC_i^t)$$

where PLP_i^t is the per capita production of pulp in region i at time t, GRP_i^t is the per capita GRP in region i at time t (in constant prices), $PLPB_i^t$ is the average per capita production of pulp in region i for three years preceding t, and RWC_i^t is the per capita consumption of roundwood in region *i* at time *t* (it should be mentioned that roundwood and pulp consumption denote industrial rather than personal consumption).

More than 500 equations have been estimated using historical data for the period 1960–1977; 160 of these were used to construct the model, according to the best statistical fit.

The following variables are treated exogenously in the model: (1) level of economic development in the regions, defined by GRP per capita (scenarios); (2) population in the regions (scenarios); (3) forest resources (to be endogenized subsequently).

The main endogenous variables in the model are (1) production and consumption of raw materials and pulp and paper products for each region; (2) trade flows between the regions; and (3) absolute and relative international prices of raw materials and pulp and paper products.

The model structure is presented in Figure 4. Logically it follows the sequence of the chemical processing of wood: roundwood, pulp, paper products. Structurally these blocks are identical: each consists of a production subsector, a demand subsector, a prices and trade subsector, and a consumption subsector. Three final commodities are specified in the paper products block: newsprint, printing and writing paper, and other paper and paperboard.

Model performance is based on the equilibrium of the world market. The supply and demand of different products are defined separately for each region and each year. The initial value of the international prices is also defined for each step using a trend function. Then the total world production and demand are determined and it is assumed that the existence of a difference $\Delta \neq 0$ causes a deviation Δp of the price from the trend value. Δp in its turn causes changes in the value of production and demand in the regions. The price for which $\Delta = 0$ (or $|\Delta| < \delta$) is taken as the international price. The regional demands corresponding to this price are taken as consumption; that is, the excesses of production over demand form a pool which is then distributed among the regions in which demand exceeds production. In cases where equilibrium cannot be reached during the period studied, the value of over-(or under-)consumption ΔC is defined in each region; this value then influences demand in the following year. This logical structure made possible the creation of a dynamic simulation model which gives yearly results for the endogenous variables. The model parameters have been adjusted to fit the historical trends from 1964 to 1977.

5 RESULTS

Some preliminary results obtained with the model are presented in Tables 4–7. Table 4 shows production and potential consumption of pulp in the seven regions till 1990. Tables 5, 6, and 7 show the figures for newsprint, printing and writing paper, and other paper and paperboard, respectively. Population forecasts have been taken from UN projections while the rates of growth of GRP per capita are based on Leontief's study (Leontief, 1977). The results should be treated with caution as the model is still in the process of development.

TABLE 4 Model results for pulp (millions of tonnes).

	1980		1985		1990	
Region[a]	Production	Potential demand	Production	Potential demand	Production	Potential demand
1	12.7	12.2	16.7	16.1	21.4	20.5
2	3.9	5.0	4.5	6.1	5.2	7.2
3	10.3	19.0	11.9	21.3	13.6	24.0
4	16.6	11.1	16.9	11.1	17.4	11.6
5	67.4	62.5	80.5	73.7	94.4	86.2
6	14.6	15.5	17.5	18.6	20.8	21.9
7	7.6	8.4	11.0	11.7	15.8	16.4
World	133.1	133.7	159.0	158.8	188.6	187.8

[a] The regions are defined in Table 2.

TABLE 5 Model results for newsprint (millions of tonnes).

	1980		1985		1990	
Region[a]	Production	Potential demand	Production	Potential demand	Production	Potential demand
1	1.61	1.28	1.91	1.47	2.25	1.67
2	0.33	0.57	0.35	0.70	0.36	0.83
3	2.22	5.28	2.41	5.75	2.72	6.25
4	2.90	0.52	2.96	0.55	3.03	0.59
5	12.93	11.23	14.86	12.70	16.86	14.48
6	3.60	3.68	4.39	4.37	5.29	5.15
7	2.54	3.81	3.79	4.97	5.61	6.75
World	26.13	26.37	30.67	30.51	36.12	35.72

[a] The regions are defined in Table 2.

TABLE 6 Model results for printing and writing paper (millions of tonnes).

	1980		1985		1990	
Region[a]	Production	Potential demand	Production	Potential demand	Production	Potential demand
1	1.42	1.53	1.89	1.99	2.55	2.59
2	0.94	0.94	1.04	1.05	1.14	1.16
3	10.86	11.40	12.64	13.78	15.04	16.34
4	3.04	0.83	3.62	0.96	4.26	1.11
5	15.52	15.18	19.06	18.58	22.88	22.23
6	4.06	4.17	4.99	5.20	6.07	6.38
7	5.37	6.30	7.61	8.85	10.79	12.47
World	41.21	40.35	50.85	50.41	62.73	62.28

[a] The regions are defined in Table 2.

TABLE 7 Model results for other paper and paperboard (millions of tonnes).

Region[a]	1980 Production	1980 Potential demand	1985 Production	1985 Potential demand	1990 Production	1990 Potential demand
1	7.99	7.52	10.14	9.48	12.60	11.70
2	4.64	5.35	5.67	6.57	6.82	7.92
3	18.54	23.34	21.37	26.95	24.41	30.82
4	6.71	2.12	7.69	2.43	8.74	2.77
5	44.74	41.23	52.32	47.77	60.30	54.60
6	14.75	14.82	18.02	18.10	21.73	21.84
7	12.16	14.94	17.04	20.80	23.94	29.07
World	109.53	109.32	132.25	132.10	158.54	158.72

[a] The regions are defined in Table 2.

6 CONCLUSIONS

In the last few years global modeling activities have shown a trend toward dealing with practical problems. In our study we have tried to apply the global modeling approach to the modeling of one sector of world industry. A future objective in our studies will be the linking of the global model with a national model of the same sector. The global model will feed the national one with data about world prices, trade flows, and demand patterns and thus will be one of the tools for planning the future development of this sector of the national economy.

REFERENCES

Häfele, W. and Basile, P. (1979). Modeling of Long-Range Energy Strategies with a Global Perspective. Operational Research '78. North-Holland, Amsterdam.

de Hoogh, J., Keyzer, M., Linnemann, H., and Van Heemst, H.D.J. (1975). Food for a growing world population. In G. Bruckmann (Editor), MOIRA: Food and Agriculture Model. CP-77-1. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Leontief, V. (1977). The Future of World Economy. United Nations, New York.

Moiseev, N. (1977). Un système de simulation homme–machine pour les études globales des déséquilibres thermiques. In the Proceedings of the World Conference, "Towards a Plan of Action for Mankind", Vol. 4. Pergamon, Oxford.

Panov, O. (1978). Global modeling and social management. New trends in mathematical modeling. In the Proceedings of an International Seminar on Trends in Mathematical Modeling, 2nd, Jablona, December 1974. Ossolineum, Wrocław.

Panov, O. and Dobrinsky, R. (1979). Global Modeling and the Management Problem. Institute of Social Management, Sofia. (In Bulgarian.)

Persson, P. (1974). World Forest Resources. Review of World Forest Resources in the Early 70s. Skogshögskolan, Stockholm.

Persson, P. (1977). Scope and Approach to the World Forest Resources Appraisal. Skogshögskolan, Stockholm.

Richardson, J. (1978). Global modeling. Futures, 10 (5, 6).

DISCUSSION

Asked by Parker *how trade is represented in the model* Dobrinsky *replied that it is simply the difference between production and demand in any one region, independent of prices – "region" in this case meaning a part of a country and not a group of nations.*

Climate, Air Quality, Energy

THE PROSPECT OF A GLOBAL WARMING AND STUDIES OF ITS SOCIETAL IMPACTS

William W. Kellogg
Aspen Institute for Humanistic Studies and National Center for Atmospheric Research*, Boulder, Colorado (USA)*

1 INTRODUCTION

In considering the course that society may follow in the next few decades the definite prospect of a significant climatic change should loom as a major factor to be taken into account. That such a change is likely to occur is now generally accepted in the climatological community (NAS, 1977;WMO, 1979) provided that we continue to burn fossil fuels at an every-increasing rate and thereby add more and more carbon dioxide to the atmosphere. Along with a general warming of the lower atmosphere there will surely be shifts of patterns of seasonal temperature and rainfall, and this will influence food production, forestry, fisheries, transportation, tourism – the list must include practically the entire range of human activities since all are climate sensitive to some extent.

This prospect implies that some countries will, at least initially, be better off while others will be hurt. There will be "winners" and "losers", though the definition of these terms will depend on where one lives and what one does for a living. (For example, less snow saves on the costs of snow removal but puts ski resorts out of business.) How can we go about an assessment of the economic and societal adjustments that will be called for in different parts of the world? And can we (or *should* we) put some kind of price tag on those adjustments?

This paper will attempt to deal with the first question. As for the second, that of estimating the costs of a major climatic change, it will be left for others. The present Seventh IIASA Global Modeling Conference deals, at least in part, with the economic tools that may be used in the future to assess such costs. It appears that so far they have not been used this way but hopefully the thoughts expressed here will encourage some further work in that direction.

---

* The National Center for Atmospheric Research is sponsored by the National Science Foundation; study in this subject area at the Aspen Institute is sponsored by the US Department of Energy.

2 CLIMATIC CHANGE IS A REALITY

There is no question about the fact that our climate has changed many times in the past. On a time scale of tens of millions of years the planet experiences "temporary" periods (such as the present) when the poles are covered with ice all the year round, and on a time scale of hundreds of thousands of years we see "temporary" periods (such as the present) when the world is relatively warm. Our last major glaciation reached its maximum some 18,000 years ago and was followed by a period 4,000–8,000 years ago when it was even warmer than now. The last few centuries have witnessed smaller but very significant changes of climate such as the Little Ice Age of the 17th, 18th, and early 19th centuries.

Such climatic changes have usually been gradual, but they have resulted in major readjustments of people and societies. For example, the cooling trend that took place after 1200 AD following a period of more or less favorable climate accounted in large part for the tragic demise of the Norse colonies in Greenland (early in the 15th century), and the Little Ice Age caused suffering and famine throughout most of northern Europe.

These longer-term trends, referred to here as climatic change, have always been superimposed on shorter-term climatic variations. The two differ in time scale and therefore their economic and societal impacts are different. The variations, such as those causing the recent drought in the Sahel region of Africa, the cold winters of the eastern United States in 1976–1977 and 1977–1978, and the shortfall of the Soviet grain crop in 1972, etc., can be considered as quasirandom fluctuations of temperature and/or rainfall. They have occurred at various times in the past and will undoubtedly occur again. We have no way at present of predicting even a year ahead when the next variation will occur.

However, the fact that we can predict to some extent the future climatic change due to mankind's activities creates a new and unprecedented situation. Hopefully we will learn to take advantage of this ability in the years ahead.

3 HUMAN INFLUENCES AND FUTURE CLIMATE CHANGE

Prior to the 1970s there was a generally expressed doubt in the climatological community that human activities could actually affect the global climate to any significant extent. This was based on the fact that the climate system is very large and complex and that there were so many uncertainties in our theory of the causes of climatic change that it was believed that no valid conclusions could be drawn. Many of those uncertainties are still with us but the concensus is now that, if we continue on our present course, there will be global warming in the next few decades unless something unexpected intervenes (e.g. a series of major volcanic eruptions). One of the first definitive reviews of the situation was the international Study of Man's Impact on Climate (SMIC, 1971); the most recent international revisit to the question was that of the World Meteorological Organization (WMO), which convened the World Climate Conference in February 1979 in Geneva. During the second week of the conference 120 invited experts remained in Geneva to prepare statements on the main problems of climatic variability and change and their impacts on society. A Declaration (WMO, 1979) was drawn up by the participants; it states in part:

> "Man today inadvertently modifies climate on a local scale and to a limited extent on a regional scale. There is serious concern that the continued expansion of man's activities on earth may cause significant extended regional and even global changes of climate. This possibility adds further urgency to the need for global cooperation to explore the possible future course of global climate and to take this new understanding into account in planning for the future development of human society . . . .
>
> . . . we can say with some confidence that the burning of fossil fuels, deforestation, and changes of land use have increased the amount of carbon dioxide in the atmosphere by about 15% during the last century and it is at present increasing by about 0.4% per year. It is likely that an increase will continue in the future. Carbon dioxide plays a fundamental role in determining the temperature of the earth's atmosphere, and it appears plausible that an increased amount of carbon dioxide in the atmosphere can contribute to a gradual warming of the lower atmosphere, especially at high latitudes. Patterns of change would be likely to affect the distribution of temperature, rainfall and other meteorological parameters, but the details of the changes are still poorly understood.
>
> It is possible that some effects on a regional and global scale may be detectable before the end of this century and become significant before the middle of the next century. This time scale is similar to that required to redirect, if necessary, the operation of many aspects of the world economy, including agriculture and the production of energy. Since changes in climate may prove to be beneficial in some parts of the world and adverse in others, significant social and technological readjustments may be required."

Those desiring more detailed explanations of the observational and theoretical background behind the foregoing statements may find them in the World Climate Conference Proceedings (WMO, 1979) and the recent reviews by this author (Kellogg, 1979; see also Kellogg, 1977, 1978). Figure 1 presents two possible views of the future course of global mean surface temperature, the "high" estimate being based on an assumption of a continued 4% per year increase in fossil-fuel use (half of the added carbon dioxide remaining in the atmosphere) and the "low" estimate being based on the assumption that the rate of increase of fossil-fuel use becomes zero in 20–30 years and returns to the present level in 52 years. It can be argued that both these assumptions are extreme and that the most credible scenario of future fossil-fuel use must lie between them.

In summary, it now appears very likely that, barring some unforeseen occurrence, the planet will experience a gradual warming in the decades ahead. By the turn of the century the mean temperature could be higher than at any time in the past 1,000 years or more and still rising. The polar regions will almost certainly experience a larger warming than the tropics, and there will be large regional differences in the changes of temperature and rainfall. Unfortunately, at present neither our theoretical models nor the history of past climate changes can give us the detailed information we would like to have concerning these regional changes, but this situation is expected to improve in the next few years.

The societal and economic implications of this climatic change in store for the world are obviously manifold. Since there will be differences from one country to another in temperature and rainfall (or snowfall), some countries may be better off and others

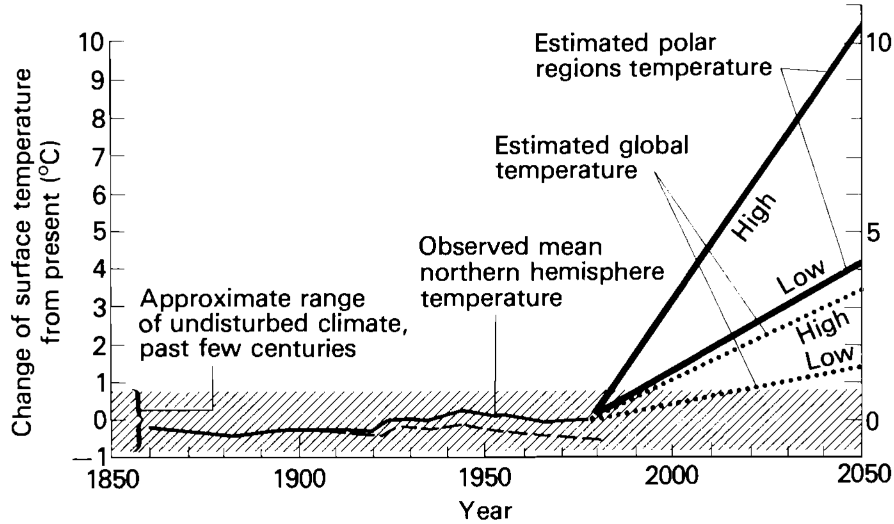


FIGURE 1 High and low estimates of past and future increases in global average surface temperature up to 2050 AD (see text for the underlying assumptions). The shaded area represents the approximate range within which temperatures have remained for the past few centuries or more and also represents the expected natural variability. The broken line is the theoretical course that the temperature might have taken up to the present if there had been no man-made addition of carbon dioxide to the atmosphere.

will suffer. There is also the possibility of a gradual change of sea level if the great ice sheets of Greenland and the Antarctic change their ice volume significantly, but most glaciologists seem to feel that this change is fairly far off on the time scale of human affairs.

4 ASSESSING THE IMPACTS OF CLIMATE CHANGE ON SOCIETY

Faced with the prospect of future climate change (a change of its own making) what will mankind decide to do about it? There are many possible courses of action (including doing nothing at all) and it is time we began to take stock of the situation. Decisions are being made today that have long-range consequences and that have a very direct bearing on "the climate problem". Examples include the choices between nuclear energy, renewable energy sources, and fossil fuels and the long-range planning for agriculture and land use in the Arctic and in low-lying coastal areas.

The US Department of Energy is sponsoring a preparatory study by the Aspen Institute for Humanistic Studies that will seek to identify the issues and define the questions that need to be answered in the next decade or so. It is too early to report on results at present but the main components of the program that will have to be undertaken are already becoming fairly clear and are outlined in the following.

It will be noted that the outline starts with the most specific and quantifiable questions and proceeds to the question of impacts of climatic change on human activities and societal structures. It is the last question which is probably the most difficult, and this is also the area that is most closely related to the present conference.

4.1 Geophysical Studies (Climate Scenarios)

The purpose of further geophysical studies of the sources and sinks of atmospheric carbon dioxide and the effects of changes in carbon dioxide levels on climate is to permit a better description of the future course of the climate if we adopt a certain energy strategy with regard to fossil-fuel use (and also our use of the world's forest resources). Carbon dioxide will surely increase if we continue on our present course, and this will lead to a general warming and shift of patterns of temperature and rainfall. We need to describe these shifts in more detail than we can now, and the following are some of the efforts that need to be pursued.

(a) We need to obtain better information on the carbon cycle in order to improve prediction of future levels of atmospheric carbon dioxide.

(b) We must define future climatic change due to increased carbon dioxide levels in terms of regional-scale changes of seasonal patterns of mean temperature and rainfall (snowfall) and also in terms of the future interannual variability of these weather elements.

(c) We must improve the way in which the oceans and the effects of cloudiness are included in models of the climate system.

(d) We must monitor the behavior of the great ice sheets of Greenland and the Antarctic and must attempt to predict their future behavior under the influence of a polar warming. This will have implications for changes of sea level.

4.2 Economic Studies (Specific Responses)

The response of certain activities to weather and climate anomalies is fairly well understood (e.g. heating requirements, the productivity of some crops, and the costs of some kinds of transportation). However, it will be a further step to extend this kind of knowledge to other sectors, to express the results in economic terms, and to extend these economic studies (models) to the effects of more gradual climatic change on a large mix of activities. The most important activities or factors to study in this context appear to be (1) agriculture, (2) forestry, (3) fisheries, (4) water resources, (5) provision of energy, (6) transportation, (7) land use, and (8) health and disease.

The effects of a change of sea level are in a somewhat different category but could be equally important in the long run.

4.3 Sociopolitical Studies

It is now clearly recognized that the response of a society to climatic variations and change depends on the structure of that society – on its economic viability, its governmental organizations, its ethical and moral beliefs, its life styles, etc. While a given drought may cause great hardship and loss of life in one region (e.g. the Sahel, Ethiopia) the same drought will only cause some temporary readjustments in other regions (e.g. the United States, Europe). It is also recognized that the ability of a population to feed itself does not only depend on the food available in the country but also on the ability of the people to buy the food (or on the ability of some agency to get it to them). Furthermore, food is not the only factor involved in the response of a society to climate change.

The problem of predicting what individual societies and the community of nations will do in the face of a global climate change is so complex that it has not yet even been well defined. Indeed it may be impossible to predict. Nevertheless, it is important that we develop methodologies that will help us to see the future more clearly and which will permit proper choices to be made.

4.4 Choices of Strategies

The ultimate purpose of this sequence of investigations, ranging from geophysical through economic to sociopolitical studies, is to permit a rational choice of national and international strategies. Long-range planning and decisions based on it are always fraught with uncertainties, but the function of the planner is to reduce the uncertainties as much as possible.

The range of strategies that appear to be open to the decision makers of the world in the decades ahead seems to be as follows.

(a) No strategy. This implies no response to the issue of carbon-dioxide-induced climatic change.

(b) Incrementalism. We can make short-term and ad hoc responses to the crises as they become evident, a process often referred to as "muddling through". This seems to be the course that is most commonly taken.

(c) Adapting to climatic change. There are a number of long-range measures that can be visualized to prepare for climatic change and to reduce its impact. These may involve flexible agricultural and forest management, water-resource development, land-use planning in coastal areas that are threatened by change of sea level, and provision of help to developing countries that may not be able to cope with climatic change.

(d) Averting the climatic change. The change could be averted if the whole world stopped (or greatly reduced) the burning of fossil fuel and the destruction of forests. Is such a move achievable? Perhaps it would be if decisions were made to reduce energy demand, to go to more nuclear and/or renewable energy sources, and to slow the reckless deforestation now going on in the tropics. It is also possible, in principle, to remove the excess carbon dioxide from the atmosphere (at great cost) or to cool the world by reducing the solar radiation absorbed (at great cost also). It is clear, however, that there is no international mechanism in existence now that could even begin to carry out and enforce such draconian measures on a worldwide scale.

5 THE MESSAGE FOR THIS CONFERENCE

We are told that the various kinds of global models that have been developed in recent years and that are the subject of this conference are generally not to be considered, by themselves, as predictors of the future. Rather, they are aids to decision making since they can give some insight into the consequences of a given set of political and economic decisions by nations or multinational corporations. Thus, given a scenario of such decisions a model can trace the reaction of the global economic system, subject of course to the limitations of the model in simulating "the real thing".

When the geophysicists and climate modelers have done some more homework in the next few years they will hopefully be able to provide the economists with a new kind of scenario – that of the climatic change induced by human activities (mostly related to energy production, which is itself subject to decisions concerning energy strategies).

It is not too soon for the economic modelers to consider how they will be able to introduce this new ingredient into their global models. It may even turn out that the future course of the world economic system cannot be described adequately without taking climatic change into account. This will almost certainly be true for projections that extend well into the next century.

REFERENCES*

Kellogg, W.W. (1977). Effects of human activities on global climate. WMO Technical Note No. 156 (WMO No. 486). World Meteorological Organization, Geneva.

Kellogg, W.W. (1978). Global influences of mankind on the climate. In J. Gribbin (Editor), Climatic Change. Cambridge University Press, Cambridge, pp. 205–227.

Kellogg, W.W. (1979). Influences of mankind on climate. Annual Review of Earth and Planetary Science, 7: 63–92.

NAS (1977). Energy and Climate. Geophysics Research Board, National Academy of Sciences, Washington, D.C.

SMIC (1971). Inadvertent Climate Modification: Report of the Study of Man's Impact on Climate. MIT Press, Cambridge, Massachusetts.

Williams, J. (Editor) (1978). Carbon dioxide, Climate, and Society. IIASA Proceedings Series, Vol. 1. Pergamon Press, Oxford.

WMO (1979). Proceedings of the World Climate Conference (including Declaration and Supporting Documents), February 1979. WMO No. 537. World Meteorological Organization, Geneva.

DISCUSSION

From a thorough discussion between Quance *and* Kellogg *it emerged that the climatic changes to be expected within the next decade will, even under rather extreme assumptions, not lead to a general deterioration but rather to changes which will be considered favorable by some regions and unfavorable by others.*

Bruckmann *raised the question of whether or not a change from one stable state to another stable state (e.g. to another ice age or to melted ice caps) could occur within*

---

* For an excellent and extensive discussion of the issues raised in this paper, see Williams (1978), which is the proceedings of an IIASA Workshop cosponsored by the WMO, the United Nations Environment Program, and SCOPE (the Scientific Committee on Problems of the Environment) held in February 1978.

a relatively short period of time. In reply Kellogg *described the historical evidence that such changes actually did occur within geologically brief periods which, however, are long periods from a human point of view (several thousand years).*

Robinson *wondered whether one should not worry more about possible increases in climatic variability than about gradual climatic changes in one or the other direction.* Kellogg *answered that, in spite of common belief to the contrary, variability has not increased in recent decades; our present knowledge, however, does not allow us to make any predictions as yet. Even when ocean currents change (which is rather likely) these changes will occur rather smoothly, not necessarily increasing variability.*

Asked by Steger, Kellogg *clarified that both the advocates of a new ice age and those who believe in a future temperature increase might be right: the ice age might arrive within another 8,000 years, the warming within the next 100 years; there are simply different time spans involved. Among climatologists there is nowadays a rather common belief that the man-made average global temperature increase will amount to roughly 1 °C, in addition to "noise", by the year 2000. An increasing number of models are being developed so we can hope that our knowledge about climatic interactions will have improved before too long.*

ENVIRONMENTAL IMPACTS OF ALTERNATIVE ENERGY TECHNOLOGIES: EMPIRICAL RESULTS FROM A TECHNOECONOMIC MODEL (ZENCAP–SYSTEN)

René Codoni and Peter Staub
Center for Economic Research (Project Zencap), Swiss Federal Institute of Technology, ETH Zentrum, 8092 Zürich (Switzerland)

Bernard Saugy
Institut d'Economie et Aménagements Energétiques, Ecole Polytechnique Fédérale, EPFL Ecublens, 1015 Lausanne (Switzerland)

1 INTRODUCTION

Questions about the environmental impacts of various programs for the expansion of energy supplies have been at the center of debate about the suitability of the programs for application in advanced industrial economies. Nevertheless, the treatment of environmental themes has proved difficult to implement in many formal investigations which have attempted to analyze the relative benefits and costs of alternative energy strategies.

This is hardly surprising. Often the environmentalist stance has been one which allows few if any choices: the prescription of environmental protection needs is couched in terms of absolute imperatives. Nor can the assessment of environmental issues be separated from broader judgements on the appropriate patterns of economic and social development for advanced industrial economies, particularly when their relationships with developing countries are further taken into account.

The implicit assumptions of those adopting the imperatives of environmental protection are well revealed in the recent commentary from Manne et al. (1979), who write thus:

> "For energy demands to continue growing at past rates, the most likely large-scale successors to petroleum would be coal and nuclear energy. Both of these sources are opposed by environmental defense groups. Instead, in one public hearing after another, the intervenors have urged reliance upon decentralized solar and other renewable energy sources together with conservation and simpler life-styles." (Manne et al., 1979, p. 2).

This approach appears to have the advantage of a reasonably well-defined objective function. It seems to imply that technical and economic choices would be constrained by the environmental imperatives. No hint is given of the challenges associated with adapting to this position from one where petroleum-based activities have dominated the expansion of energy supplies.

This failure to explore the implications of the time needed to adjust the economic and social structures of advanced industrial economies points to one of the major shortcomings in the arguments of the strict environmentalist position. There may be many purposes in the working through of larger models dealing with energy problems. One important aspect is the elucidation of policy issues with regard to the possibilities for adaptation. For example, if the prescription for "simpler life-styles" were acceded to, questions would still remain about the employment and real income associated with this stance. Simpler does not necessarily mean lower demands for real capital outlays or simpler technologies; this is certainly not the case with the solar-energy collection and distribution cited earlier.

There is no denying the importance of environmental issues in such matters as nuclear power generation, pollution associated with the extraction of coal and its use in thermal power stations, and the provision of facilities for converting coal, oil sands, tars, and oil shale to liquid or gaseous fuels. This means the incorporation of the best available information on likely new processes as well as on existing processes into any assessment of energy requirements and how they may be satisfied.

Again notions of risk and uncertainty pose serious problems for any study. The strict environmentalist position appears to treat risk as an absolute restraint; i.e. any risk is an unacceptable risk. Nevertheless, there is uncertainty about the rate of progress in the development of capacities to use solar energies and the means of improving the conversion efficiency of existing methods of production with stricter environmental requirements.

In fact dilemmas abound throughout the analysis of energy strategies in relation to environmental issues. This is not surprising. Accordingly, the work undertaken by the two Swiss project groups in Zürich and Lausanne seeks to develop means of examining the choices in strategies in the energy spheres. What is being sought is an understanding of the possibilities in the technical and economic fields, with allowance for the inevitable interplay between them.

The joint effort is directed at the devising of a comprehensive model, or rather a set of interlinking models, which will permit the interactions to be viewed under a variety of assumptions. In this paper the main thrust of the argument is about environmental features as they bear on energy developments. However, it should be clear that this is but one aspect of the work, however important it may be to public-policy themes. This requires an elaboration of the basis of the model before the main topic of linking energy and the environment is addressed. Only in this way is it possible to see what is being attempted by the two project groups and how the main features of this joint effort fit together.

The presentation will be in three parts, which for the present purpose may be labeled "frame", "link", and "case" respectively. The frame part (Section 2) deals with the macroeconomic simulation model and its core, i.e. the energy-oriented input–output system. The link part (Section 3) describes the technoeconomic interface, i.e. conversion and adaptation procedures between the technical and economic sides of the joint work. Finally, the case part (Section 4) will demonstrate in some detail how environmental characteristics of energy technologies are captured by means of formalization and quantification of such features. We end the presentation with some remarks on the repercussions of alternative techniques of assessing environmental impacts with respect to variables of the macroeconomic simulation model.

2 THE FRAME

Given the explicit environmental topic of the present conference, this part of the paper will be rather brief; for more detailed accounts of the work the reader is referred to the respective project materials (Becker et al., 1977; Codoni and Kirchgässner, 1978; Hogan, 1979; Kappel, 1980). The section is arranged as follows: we describe the setting of the work, identify the specific questions addressed by the project, explain the type of models used, and, finally, spell out some features of its main elements.

2.1 The Setting

The main purpose of the joint program is an analysis of the impact of changing energy requirements on the economy and on the choices of techniques available for the provision of energy to industry, commerce, transport, and households. The study is designed to show the implications for capital requirements arising from changes in the sources, costs, and technologies associated with the satisfaction of energy needs.

The work of the two project groups proceeds semi-independently. Project Systen deals with many technical aspects of energy production and utilization as well as taking account of social, institutional, environmental, and other restraints on performance. The work of Project Zencap is directed towards the development of a long-term economic model which reflects the application of simulation techniques. There is a close link between the two projects insofar as the Lausanne (Project Systen) analysis of technical choices in energy production provides essential information on potential investment in energy capacity. This is responsive to economic influences insofar as both capital-cost and current-cost elements enter the calculations.

The major objective of the Zencap model is the determination of the impacts of changing energy requirements on the economy, taking into account the repercussions of changing economic circumstances on technical choices. The general form of the Zencap model is quite ambitious since it combines input–output techniques and econometric analysis reflecting regression studies with simulation procedures.

2.2 The Questions

Simplifying somewhat, the long-term capital requirements of alternative (i.e. different) energy strategies may be said to be the main subject of investigation of the study. In line with the logic of simulation technique, alternative energy-production scenarios, whose repercussions on the economy are of major interest, are generated.

More specifically, what are the kinds of questions the model is to answer? First, of course, is the question of the impacts of technology *choices* on overall investment and on investment structure. Care is taken to ensure that the adjustment process of the economy is not simply made to work by forcing potential disequilibria from the energy sectors onto the nonenergy sectors.

Second, how sizable is the effect on an economy when it is moving from (traditional) resource-intensive to (expected) increasingly capital-intensive energy-production technologies? It seems that in many studies this question has been dealt with at too aggregated a level, both in the analysis of the cost of providing energy supplies and in the assessment of energy demand. (In our judgement, any study operating at "world level" expected energy demand and production runs this risk. The reason is quite straightforward: estimates of the major parameters (population, energy demand, and capital outlays) all carry very substantial margins of uncertainty.)

Finally, what *sectors* of an economy are affected by alternative decisions on energy-production technology? Or, in slightly broader terms, how do investment decisions percolate through the system? Clearly, as indicated earlier, the ratio of investment cost to current cost increases with more capital-intensive production systems. Yet, in a more macroeconomic context, what happens to prices and employment may be of even greater interest. This is not, by the way, meant as a shortcut to either the funding problem (by pushing it aside) or the multiplier and other cumulative effects (by seeing them as a cure-all mechanism).

2.3 The Model Approach

In Figure 1 the aspects relevant to the Zencap model analysis are summarized. Three main components may be identified: (i) the resources–energy submodel (Project Systen) plus the input–output complex; (ii) consumption, i.e. demand for energy and other goods and services; (iii) investment plus capital formation plus finance activity. In the notation of the figure, incidentally, the overall model performs the function of a bracket which may be interpreted alternatively as keeping together or joining the main individual components.

Admittedly, the presentation of Figure 1 does not do justice to the simulation model as it presently stands. Its workings, which have been spelt out in detail elsewhere (Kappel, 1980), may be summarized as follows.

(a) The generation of income depends on expected production in 26 sectors, of which ten relate to energy and 16 to manufacturing, commerce, and services.

(b) Investment demand is generated for the 16 nonenergy sectors by a conventional investment equation while the ten energy sectors have investment requirements generated through Project Systen.

(c) With savings determined, total demand is distributed across the final demand of the input–output matrix by equations reflecting price and income variations. In this way the relative weights of the 26 sectors change with successive iterations of the model.

(d) The supply assumptions of the model are as follows: capital stock is estimated for the base year 1970 together with estimates of the rate of utilization; additions to the capital stock reflect the subsequent investment performance in the 26 sectors together

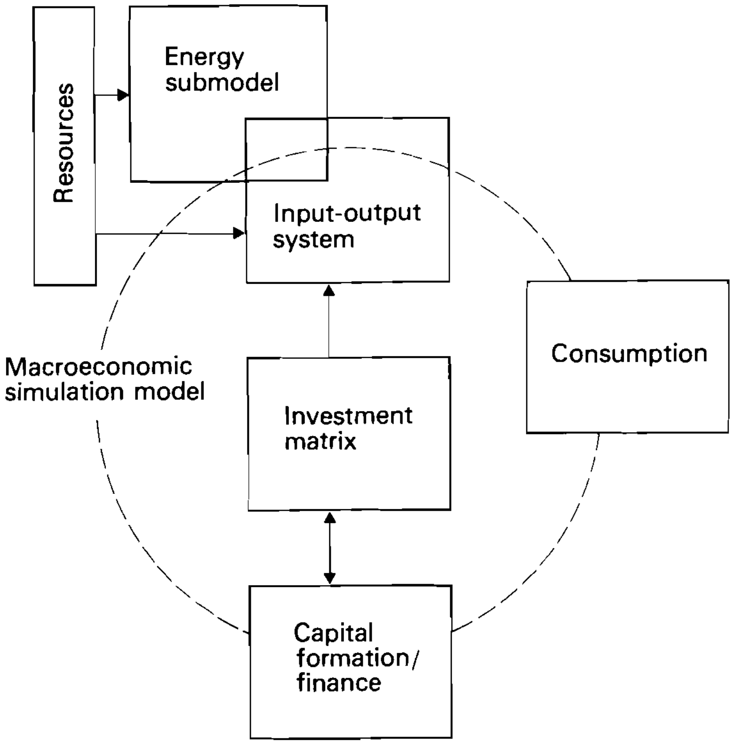


FIGURE 1 Project Zencap: main components of the macroeconomic simulation model.

with a provision for obsolescence; labor supply is treated as exogenous with the only potential variability being in the rates of participation in the work force; the technical progress/efficiency features emerge from changes in the input–output coefficients.

(e) Some items are exogenous, which imposes certain restrictions on the model: import prices (including prices for crude oil and natural gas) are exogenous; exports are exogenous; while imports are a function of the level of economic activity, they may be subjected to a ceiling in certain cases (balance-of-payments and exchange-rate considerations).

(f) The procedures supplied by Project Systen are sensitive to the economic influences of interest rates and other capital costs, real and financial, and current cost, which will mainly be for labor and materials. The impact of materials cost will be large in the case of shifts to oil-based technologies.

2.4 Main Elements: the Input–Output Core

The resources/energy/input–output complex of the model is of predominant interest in the present analysis. Thus emphasis here will be on the manner in which the input–output core is fitted into the simulation model. As a point of departure, it is

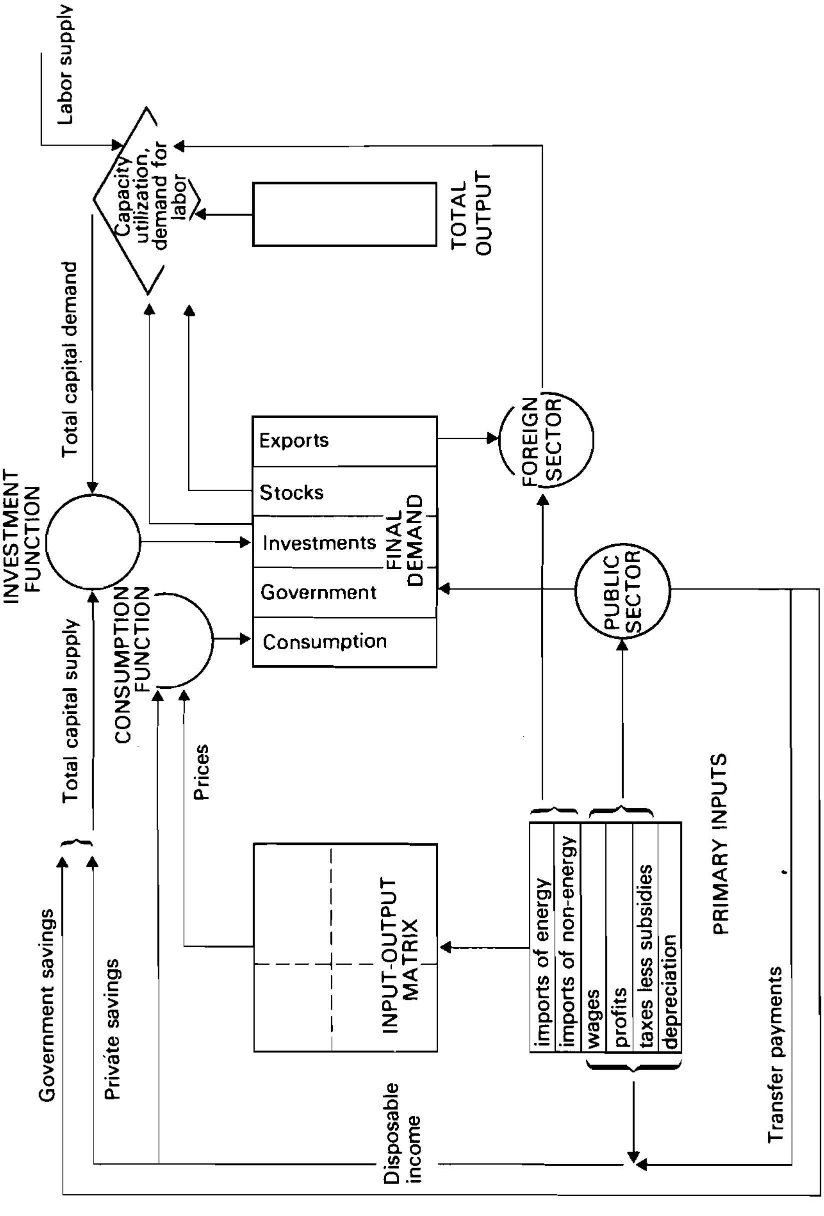


FIGURE 2 The embedding of the input–output system in the simulation model.

perhaps best to rewrite Figure 1 in input–output terms. This is done in Figure 2 where the circles denote policy nodes and the arrows mark causal and sequential interlinks.

With regard to this rewrite of the frame of the study a word should be said on the difference between a straight input–output model and a macroeconomic simulation model as it is used here, i.e. incorporating an input–output core. The basic reason for preferring the latter solution was that an input–output model frame would have been too mechanistic (or supply oriented) as regards the process of capital formation. Thus it inevitably would be rather restrictive in capturing the repercussions of energy–economy interactions.

What are the characteristics of what we have labeled an "energy-oriented input–output matrix"? First, in singling out energy sectors it does not arrange sectors of the economy by energy intensity; rather, it distinguishes between energy and nonenergy sectors of the economy. Thus it inevitably gives the energy sectors a greater average weight (in terms of the number of sectors in the total) than would standard input–output analysis.

TABLE 1 The sector classification of the input–output matrix of Project Zencap.

Energy	Industrial
E1 Hydrocarbons	I1 Mining
E2 Coke	I2 Steel
E3 Gas	I3 Nonferrous metals
E4 Solid fossil fuels	I4 Plastic and rubber
E5 Heating oil	I5 Chemicals
E6 Transportation oil	I6 Construction
E7 Electricity	I7 Machine building
E8 Low-temperature thermal energy	I8 Motor vehicles
E9 High-temperature thermal energy	I9 Transport machinery
E10 Miscellaneous	I10 Electrical engineering products
	I11 Metal products
	I12 Nonmetal products
	I13 Food and agricultural products
	I14 Rail and road transport
	I15 Air and ship transport
	I16 Services

The ten energy and 16 nonenergy sectors of the input–output system are listed in Table 1. Since the study aims to trace the development of the (energy-production) system over time the reason for the specific detail is quite straightforward: both the effects of new technologies and the effects of changes in production techniques can thus be entered into the system explicitly.

The input–output system has so far been implemented for the Federal Republic of Germany for the year 1970 (Becker et al., 1977). The energy-sector data (over all columns) are alternatively expressed in physical units (tons of coal equivalent, tce) and in monetary units (DM). Furthermore, parallel to the current-account matrix, a capital-account matrix has been established. The latter actually amounts to a breakdown of total-investment figures (as expressed in the respective final-demand vector) by recipient sectors.

Partitioning the matrix, we have four major transaction areas which, moving clockwise, are between energy sectors, deliveries of energy to industry, intraindustry transactions, and deliveries of industry to energy sectors. Figure 3 depicts this schematically, together with the capital-account matrix, the top-band elements of which are all zero (the energy industry does not produce any investment goods).

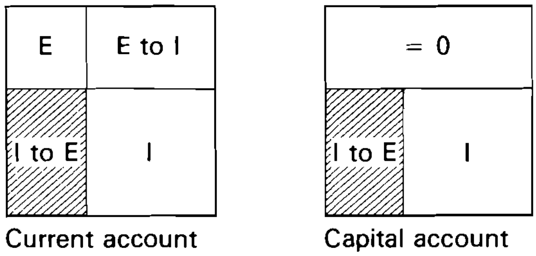


FIGURE 3 The major transaction areas of the input–output system: E, energy sectors; I, nonenergy sectors; 0, all elements are zero.

On both the current and the capital account, the industry to energy-sector transactions are of particular interest. The reason for this parallel analysis follows from the interest of the study in capturing the structural shifts towards more capital-intensive energy-production systems. Clearly, the effects of such shifts are best made explicit if the recipient sectors are at the same level of disaggregation.

2.5 Main Elements: Demand and Investment Function Estimates

On the other two major components of the Zencap simulation model – private consumption and investment demand – the theoretical assumptions are tested by econometric analysis. The respective parameter estimates, which must conform with the logic of medium- to long-term simulations, are subsequently inserted into the overall model.

The private-household demand model must provide direct and cross-price elasticities of the major demand categories as well as income elasticities of demand. The theoretical approach for the description and estimation of household behavior is based on the translog utility function. This procedure permits estimation of the respective consumer-behavior features – the three types of elasticities – without any of the restrictive assumptions on the variability of elasticities that were typical of earlier approaches. Inputs to this analysis are "disposable" income and the price-index series for the demand categories considered whereas output consists of the shares that each category holds in total consumption. Model specifications have been tailored to the needs of the particular analysis; as is also the case with results, they have been documented in supporting papers to Project Zencap (Kirchgässner, 1979a, 1980).

Investment functions, in turn, have to satisfy two requirements: first, they must be so conceived as to suit a model with a long-term perspective; second, to reflect potential "capital crunches" they must include the interest rate as an explanatory variable. Given the nature of the overall model approach, the investment demands of the energy and the nonenergy sectors must be considered separately: whereas the latter is to be used to forecast investment behavior, the former typically is the outcome of specific energy-policy scenarios. Thus only investment functions of the nonenergy sectors are estimated; in particular, they must capture the reactions of these sectors to the implementation of different energy technologies or technology scenarios. For details, the reader is again referred to the respective supporting papers (Kirchgässner, 1979b).

3 THE LINK

As schematically expressed in Figure 4, the economic system (i.e. the macroeconomic simulation model of Project Zencap) and the energy-production system (i.e. the technology allocation algorithm RETINE and the data bank Carten A) are linked through a number of variables. Furthermore, common scenario variables (which may be of a zero-growth, minimal-overall-pollution, or any other kind) act on either system. The link between the two systems – one of which mainly operates in physical units (tce) and the other mainly in monetary units (DM) – is effected by the procedure INTERFACE (see also Staub, 1980).

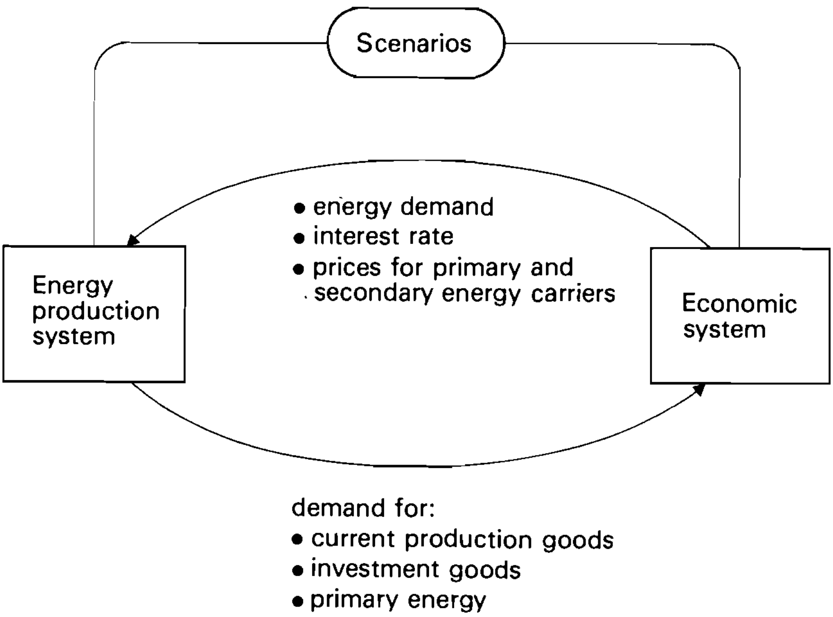


FIGURE 4 The main interlinking variables between energy and the economy.

3.1 Basic Assumptions and Main Elements

The fundamental notion of the INTERFACE procedure is that any actual energy-production system is determined by investment decisions taken several periods earlier. The role of the procedure may be seen in different terms. First, it provides the link between the technical and the economic model parts of the joint project. This is a procedure common to technoeconomic models (see Manne et al. (1979) and Energy Modeling Forum (Stanford University) (1977), which analyzes six energy models and puts special emphasis on the problem of matching the technical and economic model parts). Furthermore, it may be seen as handling the demand–resource matching of the model work. Finally, as is best demonstrated by again starting from the input–output core (in the representation chosen for Figure 3), it affects the left band of the input–output matrices, i.e. all deliveries to energy sectors, both on current and on capital account (Figure 5).

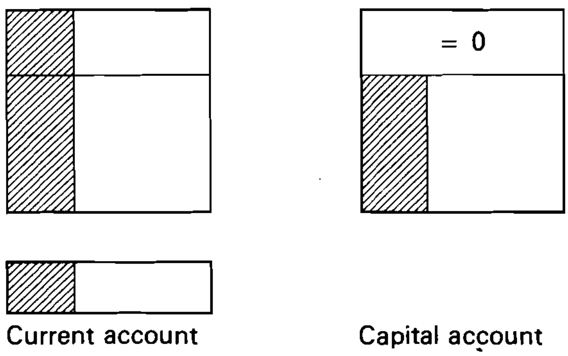


FIGURE 5 Sectors affected by INTERFACE procedures.

The layout of the INTERFACE procedure is summarized in Figure 6. As will be clear from that figure, the link between the two main models (RETINE S of Project Systen and the simulation model of Project Zencap) is effected by four submodels: Prognos, Limit, Current, and Invest. Furthermore, investment-data specifications by technology are supplied by the data banks Carten A (cost, efficiency, and environmental characteristics) (more details on RETINE S and Carten A are given in Section 4) and Carten B (input by sector of delivery, time, and finance profile) (Ruths, 1980).

At this stage the term technology, as commonly used throughout both projects, should be explained briefly. As mentioned earlier, any investment decision is, to INTERFACE, a decision to build a specific "energy-production unit". Any such unit (e.g. a hydropower station) is labeled a technology. The overall system emerging from such an approach may be represented as a network in which the technologies are the (directed) links. Thus it is possible to represent an energy carrier (e.g. electric power) by a chain of technologies (e.g. coal mining, transport of coal, coal-fired thermal power station, electricity distribution network). There are no limitations on the branching off and interlinking of such chains.

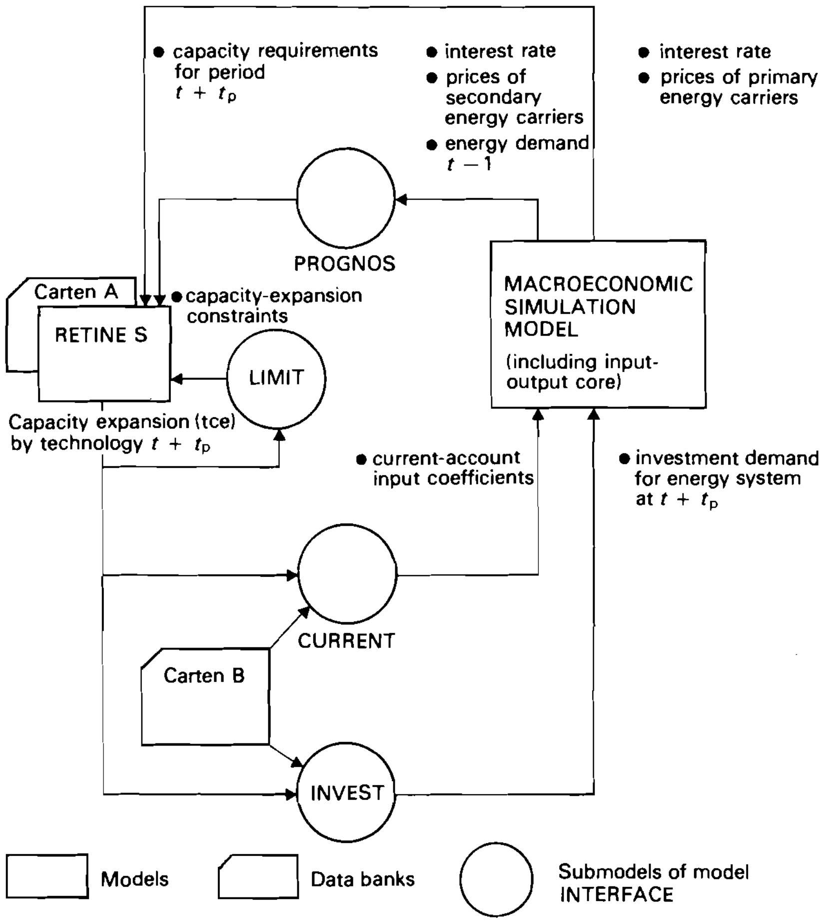


FIGURE 6 The INTERFACE procedure.

3.2 The Workings of INTERFACE

This section addresses two questions. (1) How are investment decisions actually effected by the procedure? (2) How are investment decisions reflected in the input–output system?

3.2.1 Investment-Decision Simulations

The logic applied stipulates that investment decisions of period t only become available as productive capacity after some time t_p. This in turn implies that investment decisions must be based on expected economic activity over the planning period t_p. (To be formally correct one should state that at period t the model only specifies what productive capacity should become effective between periods $t + t_p - 1$ and $t + t_p$.) New productive capacity, by the way, alternatively replaces old production units or increases the capacity of single technologies.

3.2.1.1 Capacity-Demand Forecasts. The basis for investment decisions is supplied by the submodel Prognos, which contains the following information: (i) the required productive capacity for the ten energy carriers (the ten energy sectors of the input–output core) at period $t + t_p$ (accounting for phased-out installations, this permits the calculation of the total new capacity to be provided); (ii) projected prices of primary-energy carriers (chains with a low share of primary-energy cost in the total cost become more attractive with rising prices); (iii) the current interest rate (chains with a low share of capital cost in the total cost become more attractive with a rising interest rate; furthermore, a rise in the interest rate reduces total investment activity and increases the rate of capacity utilization); (iv) scenario variables attaching certain "attractivities" to certain technologies (e.g. the specific environmental cost incurred by a technology).

3.2.1.2 Supply Constraints. The investment-goods industries are only capable of absorbing increases in demand to a limited degree. This implies, for each technology to be produced, that there is a ceiling to the real increment in productive-capacity installation. This fact is accounted for in the submodel Limit which calculates the respective ceiling values. The procedure utilizes trends, lags, and other empirically observed features of capacity growth.

The data bank Carten A in turn furnishes the (quantitative) characteristics of the energy technologies in question. The technical supply optimization is then effected by the program RETINE S. The result of this optimization is a vector of energy flows, the components of which are the flows in all technologies. From this vector the total new productive capacity to be provided may be calculated; it corresponds to the new energy investment needed by kind and size.

3.2.2 Impacts on the Input–Output System

Investment decisions affect the input–output system at two points: first, they determine energy-sector demand for investment goods by supplying sector (the shaded area of the capital-account matrix of Figure 5); second, they affect all input coefficients of the energy sectors since these coefficients reflect the energy technologies that are actually in use (the shaded area of the current-account matrix of Figure 5).

3.2.2.1 Energy-Sector Investment Demand. Investment decisions taken at time t influence investment-goods demand over the whole of the period from t to $t + t_p$. The submodel Invest records the investment-goods demand by year and supplying sector. The data source for this submodel is the data bank Carten B. The investment demand of the nonenergy sectors, however, is taken from the econometric estimates of industrial investment demand of the simulation model. The total investment demand (the respective final-demand vector of the input–output system) is obtained by summing the respective entries in the capital-account matrix (which may stem from either or both sources).

3.2.2.2. Changes in Current-Account Input Coefficients. Given the lead of investment decisions over the availability of new productive capacity, changes in the current-account input coefficients of the energy sectors only become effective at period $t + t_p$. This modification is handled by the submodel Current. The new coefficients for the period

$t + t_p$ are a weighted mean* of the coefficients at year $t + t_p - 1$ and those of the new installations, the latter being drawn from the data bank Carten B. It should be noted that this calculation can be done well ahead (i.e. at period t) of the period at which the modified coefficients are required (i.e. at period $t + t_p$).

4 THE CASE

Environmental aspects enter the present analysis at the level of energy-strategy generation. As has been spelt out already, this is dealt with by Project Systen. Except for a few occasional glimpses, however, Systen's contribution has so far only been referenced in a black-box fashion (as the resources–energy submodel in Figure 1, the energy-production system in Figure 4, or RETINE S + Carten A in Figure 6). Before entering the discussion on how the environmental dimension is accounted for in the work we must therefore crack the energy-strategy generation black box (see also Saugy, 1979).

4.1 Energy-Strategy Generation: Objective and Method

The objective of Project Systen, through a coherent string of technological and other characteristics, is a comprehensive assessment of alternative energy strategies such as might be required by decision makers. Accordingly, technology mixes that are able to satisfy a given energy demand (at one point in time) are described in terms of the technical performance of the system ("efficiency"), economic impacts (via investment), environmental consequences (such as emission, land use, safety), and institutional changes induced by increasingly centralized energy-supply systems.

The known potential of new technologies alone will not permit continued economic growth without important structural changes in energy-consumption patterns. Thus a thorough analysis of energy consumption (by type of user and by type of use) becomes necessary. For this purpose a model is developed which analyses existing and potential technologies that are capable of satisfying direct individual and direct industrial energy demand for goods and services. Indirect energy demand is estimated through information from the input–output system of Project Zencap. Direct energy demand is estimated through econometric demand analysis. It should be noted that the model is able to handle a variety of structural options such as the choice between light residential construction requiring air-conditioning and energy-saving conceptions of residential construction.

---

* With $\kappa(t \ldots)$ standing for the productive capacity at period $t \ldots$, δ for the "weight" of the existing installation, γ for depreciation, and α^* for the input coefficients of the *new* installations, we have

$$\delta = \kappa(t + t_p - 1)(1 - \gamma)/\kappa(t + t_p)$$

Thus the input coefficients α at period $t + t_p$ become

$$\alpha(t + t_p) = \delta\alpha(t + t_p - 1) + (1 - \delta)\alpha^*$$

Variants of technology mix for a given demand are generated by a flow allocation model. An algorithm of proportionate allocation, comparable to the finite-element method of mechanical engineering, is adopted to treat an openly structured energy network. Open structuring makes it possible to introduce any new technology or group of technologies into the network. Furthermore, the approach is able to treat interlinked national or regional networks.

Together with the program called RETINE, the algorithm adopted allocates the choice of a technology mix in proportion to the attractivity of each technology. It allows for specifications such as "the more attractive a technology, the more it is used" or "the most attractive technology chain will be used". The attractivity can be defined as the inverse of cost or thermal pollution or can be expressed by any objective function that adequately accounts for various technology characteristics (as assembled in the data bank Carten A).

4.2 The Workings of the Technical Model

In order to avoid confusion with other model elements of the joint project we will speak subsequently of the technical model (or, to be more specific, the technoenvironmental module) when referring to the work of Project Systen. This term designates the whole of the methods and data used in quantitative energy-strategy generation. What, in brief, are the inputs, the outputs, and the tools of the technical model?

The inputs to the technical model are the following items: (a) energy demand (projections); (b) prices of imported energy and of goods required by the energy system; (c) technology characteristics (costs, efficiencies, environmental impacts); (d) the network of the energy system, containing all disposable technologies.

The output of the technical model is an energy strategy which is expressed in energy flows by technology (output per unit of time). From this are calculated (a) total costs, (b) capital requirements, and (c) emissions and other environmental impacts.

The main tool, apart from more technical manipulations, is the program RETINE, which combines the attractivities of and the constraints on technologies in generating an energy strategy. Its core is an optimization algorithm which, in contrast to most approaches, is not of a linear programming variety but does allocate technologies in proportion to their attractivities.

4.3 Main Elements: the Technology Network

The technology network is an account of all the transformation, transport, distribution, and storage technologies of a specific energy system. In the network, technologies are represented as directed links. The layout of the network is depicted in Figure 7. It is fundamental to this representation that, at both the resource and the demand levels, energy is grouped by functional classes. For resources the representation distinguishes between mechanical, chemical, and thermal origins. Demand categories are special processes (e.g. lighting and electrolysis), mechanical processes (e.g. engines), low-temperature heat (e.g. residential space and water heating), and high-temperature heat (e.g.

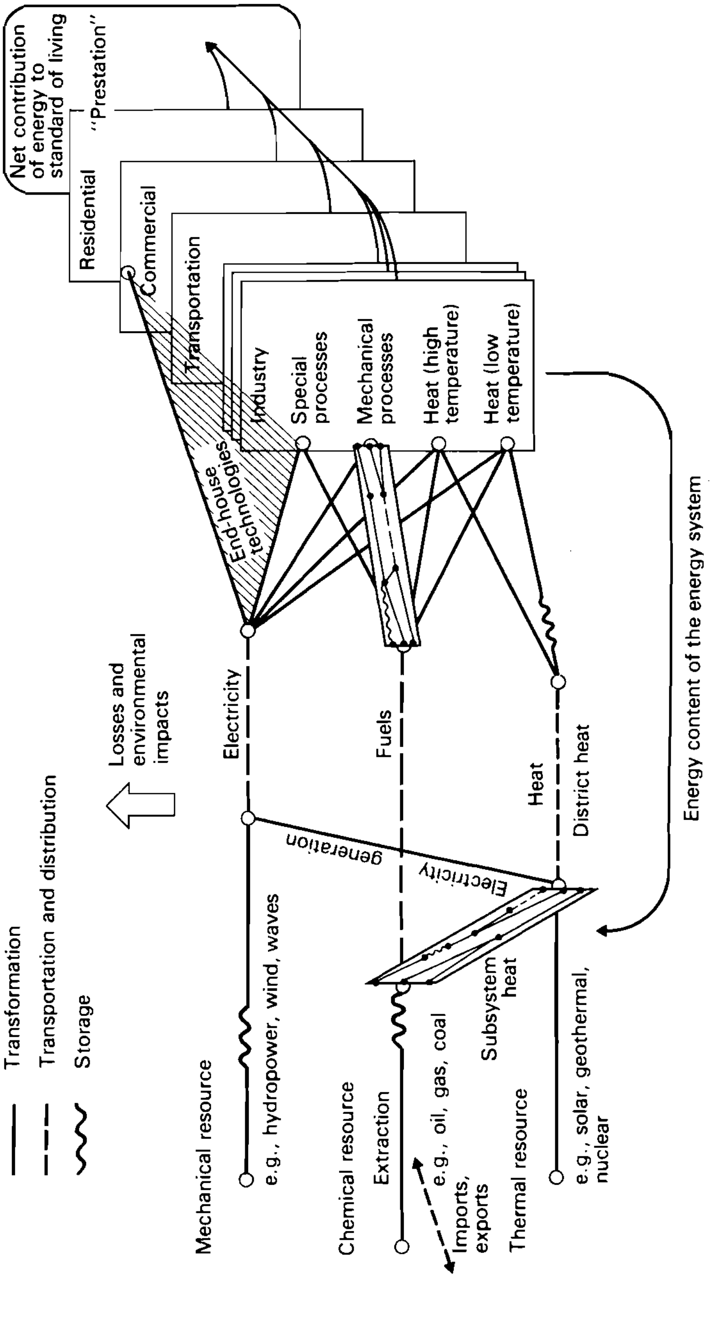


FIGURE 7 A representation of the technology network.

thermochemical processes and process heat ("steam")). At the demand level the system further distinguishes by type of sector (i.e. industrial, transportation, commercial, and residential use).

At this point one may wish to introduce the notion of "useful (energy) consumption". This can be defined as that part of energy demand directly contributing to the standard of living of individuals (e.g. the energy of light emitted by a source). Correspondingly, the remainder (i.e. the total energy consumed by that source minus useful consumption) would be labeled "nonuseful" consumption. It originates in imperfections of conversion, distribution, and storage techniques (losses on current account). To this must be added the capital-account losses, i.e. the depreciation of the energy content of the system concerned. Clearly, one aim of technical development is to reduce the share of nonuseful energy consumption.

Present energy-consumption statistics give data for current energy consumption by major category. Their distinction between useful and nonuseful energy, however, is not identical with the concept described here. In particular the losses of end-use technologies are recorded under "useful consumption". In contrast, depreciation of energy content is not recorded at all. Instead, current energy consumption of the investment-goods industries is given. This is at best a very rough proxy for depreciation of energy content (on this problem see Toinet, 1978). At the operational level the analysis must obviously be based on available data. In interpreting results, however, the concept explained earlier is kept in mind.

For longer-term considerations (and, in a way, for any crisis scenario as well) even the concept of useful energy, as against end-use energy, is restrictive. Rather than being a fundamental demand category, useful energy is an agent providing a certain service. For example, in the casé of refrigerators the prestation is food conservation, useful energy the energy extracted from the cooling space, and end-use energy the energy actually consumed by the refrigerator. Food conservation, presently done by refrigeration, may in the future be effected by, for example, oxygen-free storage. Working at the end-use level only thus neglects substitution possibilities between the end-use and prestation points.

4.4 Main Elements: the Data Bank Carten A

The data bank Carten A lists some 150 technologies. Table 2 gives a specimen data sheet for one specific technology – a 1000-MW(e) thermal power plant. The data sheet contains the following information (EPFL–IPEN–Projet d'Ecole Energie, 1979): (a) operational characteristics; (b) costs; (c) efficiency data; (d) emissions (into waters, into the air, and other); (e) health hazards; (f) cost of emission abatement; (g) market-penetration characteristics.

4.5 Main Elements: the Proportionate-Allocation Algorithm (Saugy, 1979; Saugy et al., 1977)

The proportionate-allocation algorithm is best illustrated by a simple example (Figure 8(a)). We assume that two technologies, both starting from the same source,

TABLE 2 The data bank Carten A: a specimen data sheet[a].

PROGRAMME CARTFN - IPEN

THERMO-ELECTRIC POWER PLANT (OIL-FIRED)	NUMFRO DF LA TECHNOLOGIE NOM DF LA TECHNOLOGIE	CENTRALE THERMIQUF ELECTRIQUE A L'HUILE LOURDE 011	144
Energy Inputs : Heating Oil, Electricity Energy Outputs : Electricity	ENERGIES ENTRANTES ENERGIFS UTILES SORTANTES	HUILE LOURDF + ELECTRICITE ELECTRICITE	
	DATE DE LA VERSION	26/JUN/1978	

TABLEAU DES CARACTERISTIQUES DE LA TECHNOLOGIE

	DESCRIPTION	VALEUR	UNITE	REFFRENCES	QUALITE
OPERATIONAL CHARACTERISTICS	---EXPLOITATION---				
	TAUX D'UTILISATION (TU)	0.6850	-	PE-EPFL	3
	INDISPONIBILITF PROGRAMMEE (IP)	700.0000	HEURES/AN	PE-EPFL	3
	INDISPONIBILTTE NON-PROGRAMMFE (INP)	-	HEURES/AN	?	0
	DUREE DE VIE	30.0000	AN	PE-EPFL	2
	DUREE DE PLANIFICATION	4.0000	AN	PE-EPFL	3
	DUREE DE CONSTRUCTION	4.0000	AN	PE-EPFL	3
COSTS	---COUT---				
	CAPITAL SPFC. POUR PUIS. INSTALLEE UNITE	1520.0000	FRS/KW	PE-EPFL	1
	PUISSANCE MOYENNE UNITE (PU)	1000000.0000	KW	-	2
	CAPITAL SPEC. POUR PUIS. MOY. UNITE (CU)	2230.0000	FRS/KW	BG-1589-3	2
	FACTEUR D'ECONOMIE D'ECHELLE (X)	0.2300	-	BG-1589-3	2
	FRAIS VARIABLES SPECIFIQUES (B)	500.0000	FRS/KW/AN	SULZER+BG-1589-3	2
	TAUX DES FRAIS FIXES (K1)	-	1/AN	?	0
	TAUX D'ANNUALISATION (K2)	-	1/AN	?	0
	TAUX DES CHARGFS ANNUELLES (K)	0.0900	1/AN	BG-1589-3	2
EFFICIENCY	---RENDEMENT---				
	RENDEMENT 1 (R1)	0.3700	-	EWI11+BG-1589-3	2
	RENDEMENT 2 (R2)	0.3600	-	PE-EPFL	2
	RENDEMENT EXERGETIQUE (R3)	-	-	?	0
	PUISSANCE SPECIFIQUE INVESTIE (R4)	-	-	?	0
EMISSIONS INTO WATER	---EMISSIONS DANS L'EAU---				
	HC	-	KG/KW/AN	EWI11	0
	RADIONUCLIDES (AUTRES QUE H3)	0.0000E-6	CI/KW/AN	EWI11	1
	H3(TRITIUM)	0.0000E-6	CI/KW/AN	EWI11	1
	CHALEUR	0.0000	KW(TH)/KW	PE-EPFL(TOUR REFR.)	1
EMISSIONS INTO THE AIR	---EMISSIONS DANS L'AIR---				
	POUSSIERES	0.0400	KG/KW/AN	PE-EPFL(CHAVALON)	2
	SUIE	2.0600	KG/KW/AN	PE-EPFL(CHAVALON)	2
	NOX	2.4000	KG/KW/AN	PE-EPFL(CHAVALON)	2
	SOX	73.0000	KG/KW/AN	PE-EPFL(CHAVALON)	2
	HC	0.6000	KG/KW/AN	EWI11	2
	CO	0.0400	KG/KW/AN	PE-EPFL(CHAVALON)	2
	CO2	6300.0000	KG/KW/AN	PE-EPFL(CHAVALON)	2
	PA	0.0000	KG/KW/AN	EWI11	2
	ALDEHYDES	0.2700	KG/KW/AN	EWI11	2
	VAPEUR D'EAU	14000.0000	KG/KW/AN	PE-EPFL(CHAVALON)	2
	I-131	0.0000E-6	CI/KW/AN	EWI11	2
	KR-85 + XE	0.0000E-6	CI/KW/AN	EWI11	2
	CHALEUR	1.7000	KW(TH)/KW	EWI11	2
OTHER EMISSIONS	---EMISSIONS-DIVERS---				
	EMPRISE TERRITORIALE	0.1600	M2/KW	BG-1589-3	2
	BRUIT	-	EVB/KW	?	0
	DECHETS RADIOACTIFS (SANS COMB. IRRADIE)	0.0000E-6	CI/KW/AN	EWI11	2
	DECHETS SOLIDES INERTES	0.0000	KG/KW/AN	EWI11	2
	CHALEUR(DANS LF SOL)	0.0000	KW(TH)/KW	PE-EPFL(CHAVALON)	2
	COUPURE	-	H/KW	PE-EPFL	0
HEALTH HAZARDS	---SANTE---				
	MORTS PROFESSIONNELS	-	UNIT/KW/AN	?	0
	BLESSES PROFESSIONNELS	-	UNIT/KW/AN	?	0
	JOURS-HOMME PERDUS	-	UNIT/KW/AN	?	0
	DESASTRE POTENTIEL A GRANDE ECHELLE	-	?	?	0
	PERSONNES EXPOSEES A LA RADIOACTIVITE	0.0000	?	PE-EPFL	1
COSTS OF EMISSION ABATEMENT	---AMELIORATIONS IMPOSEES---				
	AUGMENTATION DU COUT	70.0000	FRS/KW/AN	CF TECHN. 4	3
	VARIATION DU RENDEMENT	110.0000	FRS/KW/AN	CF TECHN. 4	3
MARKET PENETRATION	---IMPLANTATION---				
	DATE DE LA COMMERCIALISATION	-	-	?	0
	NIVEAU D'IMPLANTATION EN 1975	0.2000	GW	OFEE 19/4/76	1
	LIMITE SUPFRIEURE D'IMPLANTATION EN 1985	0.2000	GW	GEK/MODAL-SPLIT	3
	LIMITE SUPERIEURE D'IMPLANTATION EN 2000	0.3000	GW	GEK/MODAL-SPLIT	4
	NIVEAU DE SATURATION (S7)	-	GW	?	0
	COEFFICIENT D'INERTIE	-	-	?	0

[a] The code for the last column (quality of data) is as follows: 0, no data available; 1, very good; . . . ; 5, very poor.

alternatively or in combination are able to satisfy a given energy demand Q_0. Next we calculate the attractivities of the two technologies which for the present purpose we define as the inverse of the unit energy production cost per unit of time (e.g. Swiss Francs per kilowatt-year). We then assume that the unit cost of technology 1 is lower than the

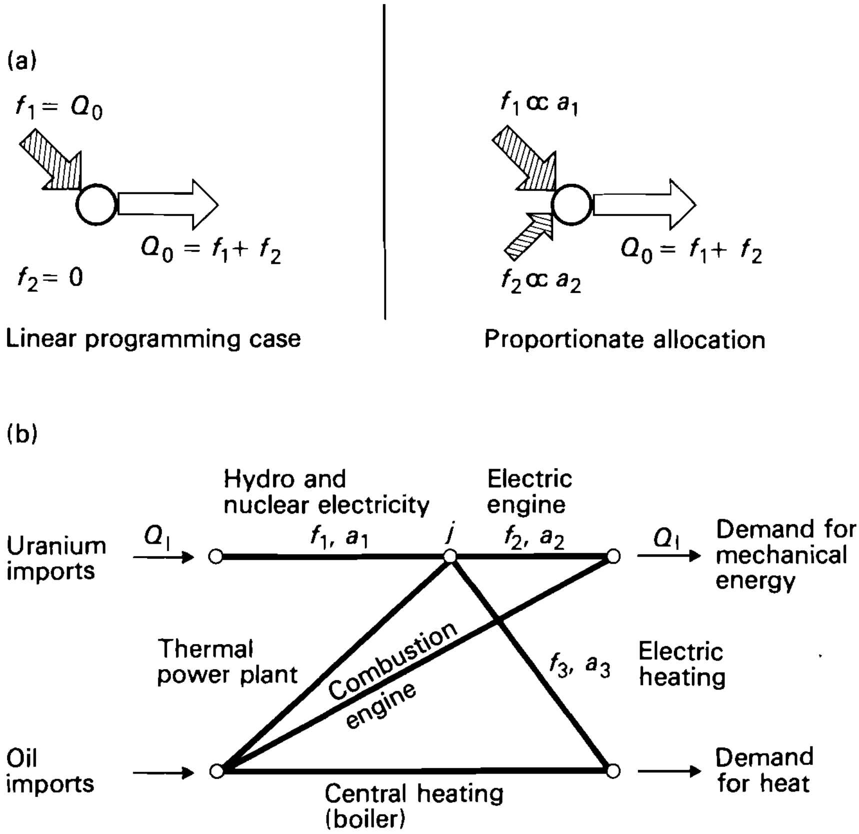


FIGURE 8 Proportionate allocation: (a) for two technologies, showing how it differs from linear programming; (b) for an energy system.

unit cost of technology 2. Linear programming would produce a cost-optimal solution by exclusively using the cheaper technology (flow $f_1 = Q_0$, $f_2 = 0$). The proportionate-allocation algorithm, however, produces a solution where both technologies are used, each in proportion to its attractivity ($Q_0 = f_1 + f_2$, whereby $f_1 \propto a_1$ and $f_2 \propto a_2$).

Accordingly the algorithm can be used for a complete energy system represented by a network with several technologies and nodes (Figure 8(b)). The outcome of proportionate allocation, as against linear programming, is again reflected in a higher-cost solution. The difference in cost may be interpreted as the diversification cost.

An extension of the proportionate-allocation algorithm is introduced by the notion of "severity degrees". This concept makes the flows approximately proportionate to the respective power of their attractivity. Thus our original proportionate-allocation case would correspond to a severity degree of 1. With increasing degree of severity this mode of calculation asymptotically approaches the linear programming solution, thus reducing the diversification cost to zero (Figure 9).

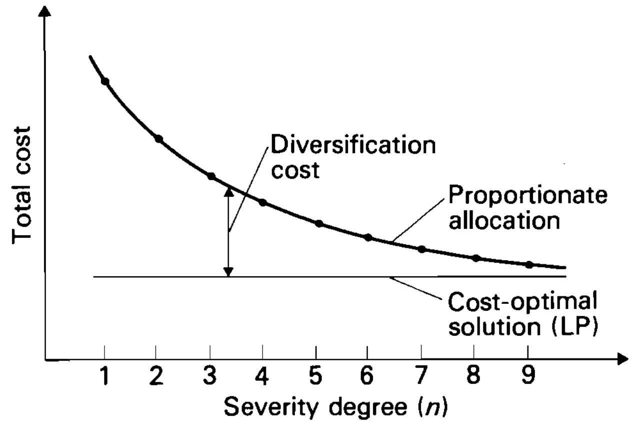


FIGURE 9 Diversification cost as a function of severity degree.

(The concept of severity degrees reflects an iteration procedure. Thus

$$f_k^n = a_k f_k^{n-1} \Delta P$$

where f denotes the flow of technology k at severity degree n (or $n - 1$ respectively), a the attractivity of technology k, and ΔP the "potential difference" between the delimiting nodes of technology k, whereby

$$P = K^{-1} Q,$$

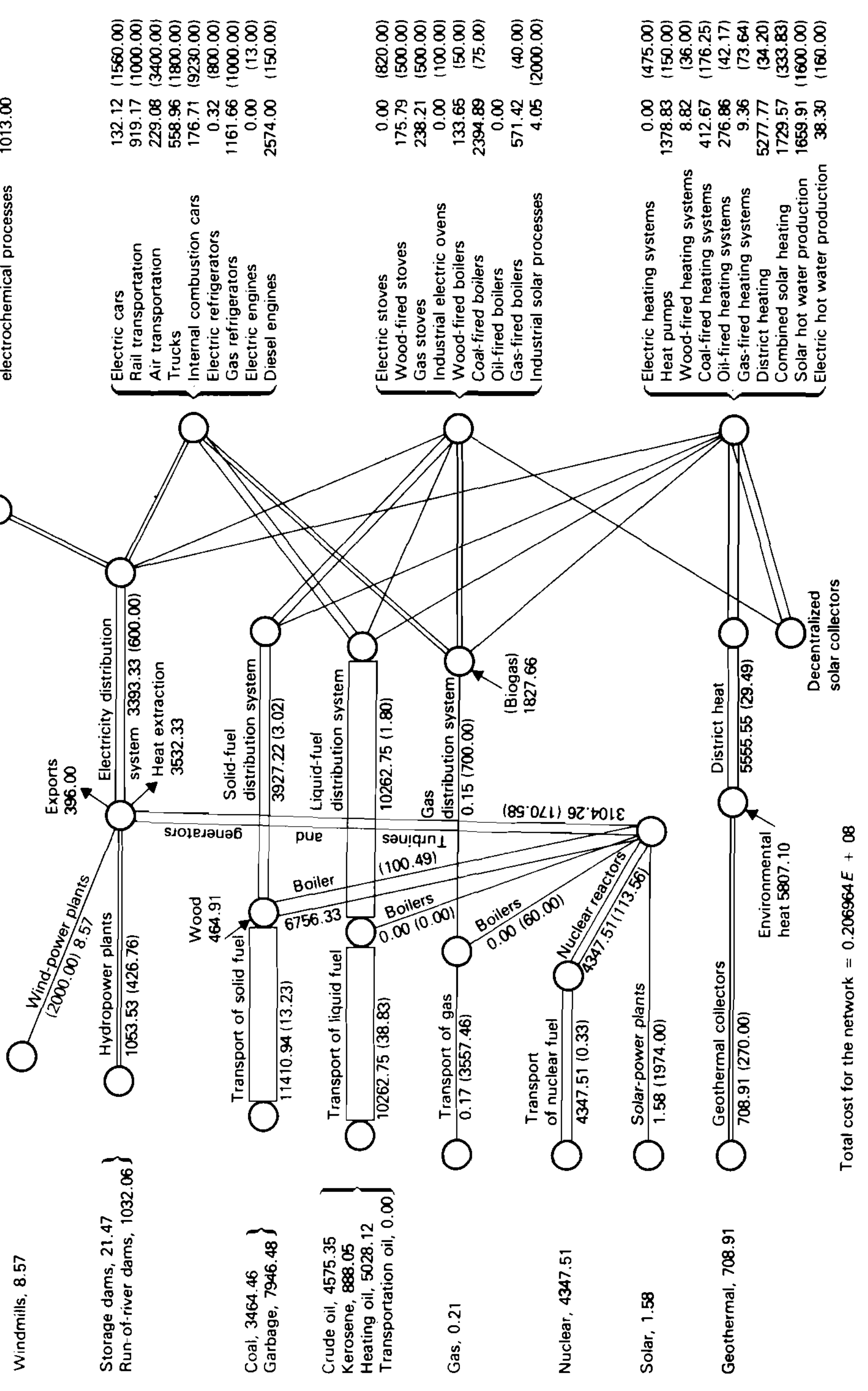
i.e. the potential P is the product of the inverted attractivity matrix K and the flow balance in nodes Q. The definition of the matrix element of K is

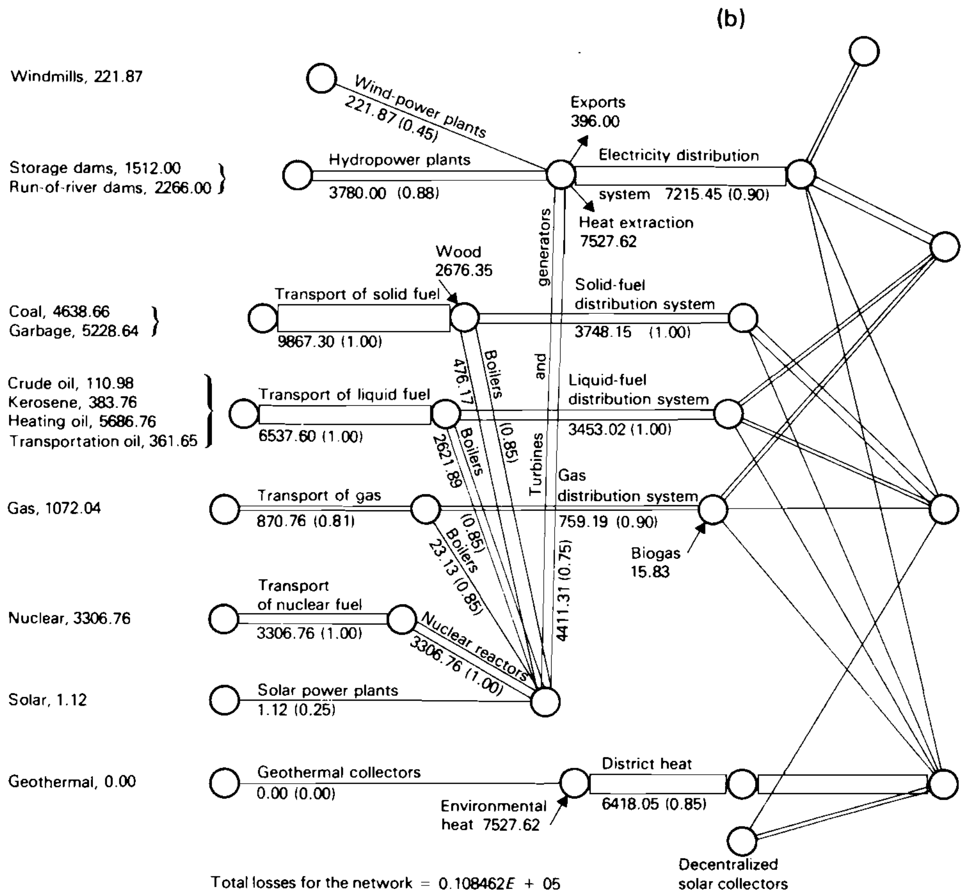
$$k_{ij} = -\sum_k b_{ij}^k \ (i \neq j) \qquad k_{jj} = \sum_{k,i} b_{ij}^k \ (i \neq j)$$

whereby $b_{ij}^k = a_k$ if technology k connects nodes i and j and $b_{ij}^k = 0$ otherwise.)

4.6 Comparing Strategies: an Illustration

Figures 10(a) and 10(b) depict the energy-flow system for Switzerland (year 2000, severity degree 3) for different attractivity assumptions satisfying the same energy demand (at the level of category totals). In the first case, which corresponds to our previous example, the attractivity is defined as the inverse of cost. In the second case the objective is to "minimize" energy losses in the production process. Thus the attractivities are proportionate to the efficiencies of the respective technologies. (The formula adopted is actually $a_k = \eta/(1 - \eta)$ where a_k is the attractivity of technology k and η the efficiency of that technology.)


(a)
Windmills, 8.57
Storage dams, 21.47
Run-of-river dams, 1032.06
Coal, 3464.46
Garbage, 7946.48
Crude oil, 4575.35
Kerosene, 888.05
Heating oil, 5028.12
Transportation oil, 0.00
Gas, 0.21
Nuclear, 4347.51
Solar, 1.58
Geothermal, 708.91
Wind-power plants
(2000.00) 8.57
Hydropower plants
1053.53 (426.76)
Transport of solid fuel
11410.94 (13.23)
Wood
464.91
Transport of liquid fuel
10262.75 (38.83)
Transport of gas
0.17 (3557.46)
Transport
of nuclear fuel
4347.51 (0.33)
Solar-power plants
1.58 (1974.00)
Geothermal collectors
708.91 (270.00)
Boiler
6756.33
Boilers
0.00 (0.00)
Boilers
0.00 (60.00)
Nuclear reactors
4347.51 (113.56)
Turbines and generators
(100.49)
3104.26 (170.58)
Exports
396.00
Electricity distribution
system 3393.33 (600.00)
Heat extraction
3532.33
Solid-fuel
distribution system
3927.22 (3.02)
Liquid-fuel
distribution system
10262.75 (1.80)
Gas
distribution system
0.15 (700.00)
(Biogas)
1827.66
District heat
5555.55 (29.49)
Environmental
heat 5807.10
Decentralized
solar collectors
Use Flow Attractivity
Lighting and electrochemical processes 1013.00
Electric cars 132.12 (1560.00)
Rail transportation 919.17 (1000.00)
Air transportation 229.08 (3400.00)
Trucks 558.96 (1800.00)
Internal combustion cars 176.71 (9230.00)
Electric refrigerators 0.32 (800.00)
Gas refrigerators 1161.66 (1000.00)
Electric engines 0.00 (13.00)
Diesel engines 2574.00 (150.00)
Electric stoves 0.00 (820.00)
Wood-fired stoves 175.79 (500.00)
Gas stoves 238.21 (500.00)
Industrial electric ovens 0.00 (100.00)
Wood-fired boilers 133.65 (50.00)
Coal-fired boilers 2394.89 (75.00)
Oil-fired boilers 0.00
Gas-fired boilers 571.42 (40.00)
Industrial solar processes 4.05 (2000.00)
Electric heating systems 0.00 (475.00)
Heat pumps 1378.83 (150.00)
Wood-fired heating systems 8.82 (36.00)
Coal-fired heating systems 412.67 (176.25)
Oil-fired heating systems 276.86 (42.17)
Gas-fired heating systems 9.36 (73.64)
District heating 5277.77 (34.20)
Combined solar heating 1729.57 (333.83)
Solar hot water production 1659.91 (1600.00)
Electric hot water production 38.30 (160.00)
Total cost for the network = 0.206964E + 08



Use	Flow	Attractivity
Lighting and electrochemical processes	1013.00	
Electric cars	24.54	(0.50)
Rail transportation	1570.40	(0.80)
Air transportation	85.24	(0.22)
Trucks	251.97	(0.30)
Internal combustion cars	83.85	(0.22)
Electric refrigerators	0.00	(1.50)
Gas refrigerators	1162.00	(1.50)
Electric engines	2054.44	(0.92)
Diesel engines	519.56	(0.41)
Electric stoves	0.00	(0.60)
Wood-fired stoves	413.77	(0.60)
Gas stoves	0.23	(0.65)
Industrial electric ovens	0.00	(0.60)
Wood-fired boilers	1688.70	(0.85)
Coal-fired boilers	911.01	(0.85)
Oil-fired boilers	485.22	
Gas-fired boilers	0.00	(0.85)
Industrial solar processes	46.07	(0.60)
Electric heating systems	0.00	(0.95)
Heat pumps	1329.85	(2.50)
Wood-fired heating systems	0.02	(0.60)
Coal-fired heating systems	0.01	(0.64)
Oil-fired heating systems	38.21	(1.00)
Gas-fired heating systems	0.00	(0.00)
District heating	6097.15	(0.95)
Combined solar heating	1335.81	(2.47)
Solar hot water production	496.15	(0.40)
Electric hot water production	1207.82	(0.92)

FIGURE 10 The energy-flow system: (a) attractivity inverse of cost (cost case); (b) attractivity proportionate to efficiency (efficiency case). Units of MW are used throughout.

4.7 Extension of the Analysis: Environment and Social Factors

The concept of attractivity, as spelt out in the proportionate-allocation algorithm, lends itself to the incorporation of a variety of factors other than simple cost and efficiency considerations. However, the fundamental problem encountered with environmental and social factors is that they are extremely difficult to quantify. There are several reasons for this. First, though we can often measure certain emissions our knowledge of their effects is rather poor. This problem grows with an increasing number of pollutants (combined effects). Second, given the large differences in individual acceptance levels, agreed emission standards are hard to come by. Finally, overriding political considerations (autarky, nonproliferation, etc.) further confuse the issues. Though for specific projects cost–benefit-type analysis based on damage caused has tackled these problems with apparent success, at a more general level the dilemma remains.

Though less comprehensive than desirable, the introduction of the pollution-abatement cost into the total cost of a technology seems to offer a way around the problem. Since pollution-abatement is only possible for a few emittors – even some of the more important impacts cannot be influenced by such measures (e.g. risk, CO_2 emission) – such a solution is hardly satisfactory.

Another way of overcoming this problem is simply to record environmental consequences of specific energy strategies. An analysis of this sort has been done on the cost and efficiency strategies presented earlier (Figure 11). However, this procedure, in line with the residual character of environmental consequences, reduces environmental options to a mere choice between evils.

4.8 The Cost–Environment Case

The combination of perception problems, heterogeneity of effects, and lack of knowledge (of global and long-term implications) makes it impossible to devise a consistent measure for environmental impacts. This said, however, there still remains the use of heuristic methods (the Delphi process) in assessing environmental impacts.

The procedure is quite straightforward: on an ordinal scale ranging from 0 to 10 each technology is assigned a value reflecting its environmental attractivity. This measure (the "environmental unattractivity index") takes the value of zero in cases of technologies with no environmental consequences and the value of 10 for the worst case. It should be noted that the judgement implied in the ranking reflects public opinion rather than scientific judgement. (The Delphi process chosen proceeds as follows: (1) the generation of energy scenarios and strategies (e.g. "cost case", solar push, greater autarky); (2) the comparison of the principal emission profiles; (3) the identification of the contribution of individual technologies to the total emissions and social cost; (4) the assignment of environmental unattractivity indexes according to overall environmental impact (non-linearity of impacts as a function of total emissions).)

The environmental unattractivity index E enters the attractivity calculation for technology k. a_k thus becomes

$$a_k = 1/c_k(1 + \lambda E_k)$$

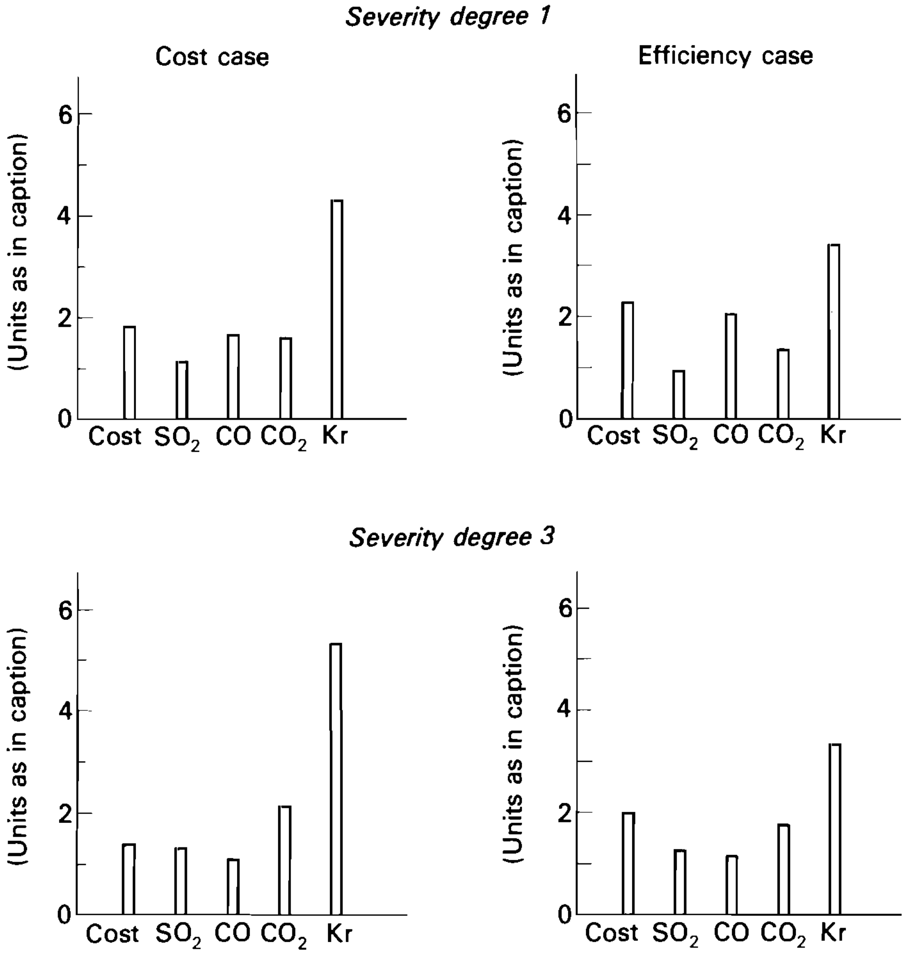


FIGURE 11 Total cost and principal emissions. The units used are as follows: total cost, 10^{11} Swiss Francs; SO_2, 10^5 tonnes; CO, 10^5 tonnes; CO_2, 10^7 tonnes; Kr, 10^4 Ci.

where c_k is the unit cost of technology k (per unit of time) as used in the cost case earlier and λ is the overall weight assigned to environmental aspects in the energy-technology assessment. As expressed in the denominator, the "total cost" of a technology now comprises cost c_k plus environmental cost $c_k \lambda E_k$. In the following, this is referred to as the cost–environment case which penalizes environmentally unattractive technologies.

The implications of environmental cost are depicted in Figure 12. Clearly the total cost of the energy system increases as λ increases. With increasing degrees of severity the total environmental costs decrease, yet without ever falling to zero. This reduction reflects an environmentally more acceptable energy system. For purposes of illustration the energy-flow system and principal emissions have been calculated for the cost–environment case (Figures 13 and 14).

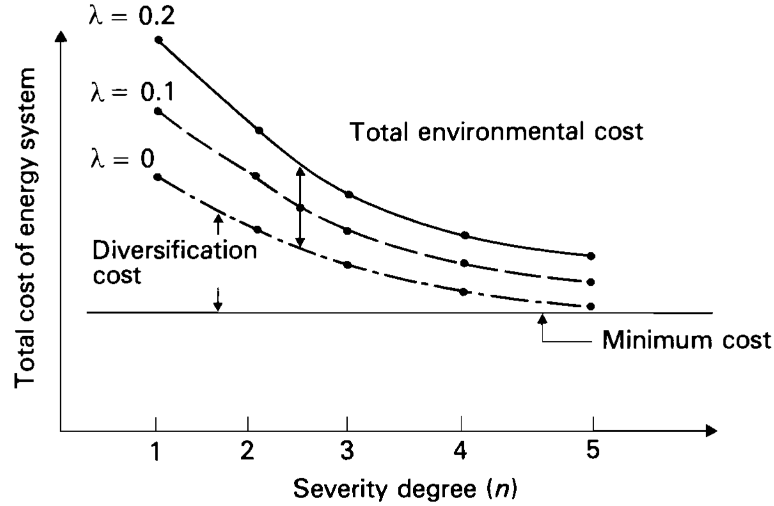


FIGURE 12 Diversification cost and environmental cost as functions of severity degree and overall environmental weight.

5 CONCLUDING REMARKS

Energy has become increasingly a theme of economic policy, if not a straight political issue. Any formalization of energy themes (or any energy model) must therefore render explicit the policy aspects of decisions. This limits the applicability of traditional techniques of analysis, be they economic or technical. The price of oil may serve as a case in point: neither by taking it as an exogenous variable nor by describing it in terms of scarcity or monopoly rent do we account for its trigger role in determining overall energy scenarios. Escaping from heavy dependence on one source of energy may well be a goal in itself. At some stage, though, one may wonder whether the extraction of crude oil in the Near East, only for it to be redeposited on a large scale in salt caverns in North America, is really conducive to such a goal . . . . (For a refreshingly heretical view on the policy problem see Reifman (1978).)

Furthermore, energy has increasingly become a subject of several disciplines. The traditional subject of physics, geology, and engineering, it has become a major subject of economics, political science, and environmental sciences as well. The list is not exhaustive. The label of pluridisciplinarity having lost some of its appeal as a cure-all method, this broader spectrum of the subject is reason for concern rather than delight. For example, the fact that, counter to the traditional understanding, "bringing electricity to the last hamlet" is not necessarily hailed as progress may well come as a shock to the engineers. People, when under shock, are likely not to react very favorably to challenges. So confusion and defensive behavior rather than cooperation may be the result. It is almost unnecessary to add that this may not help the cause.

Finally, energy is the theme of the rather heterogenous but increasingly powerful group of people concerned with the environment. Their imperative position on energy, in a first round, has led to a strong polarization on nuclear power. At present, elections

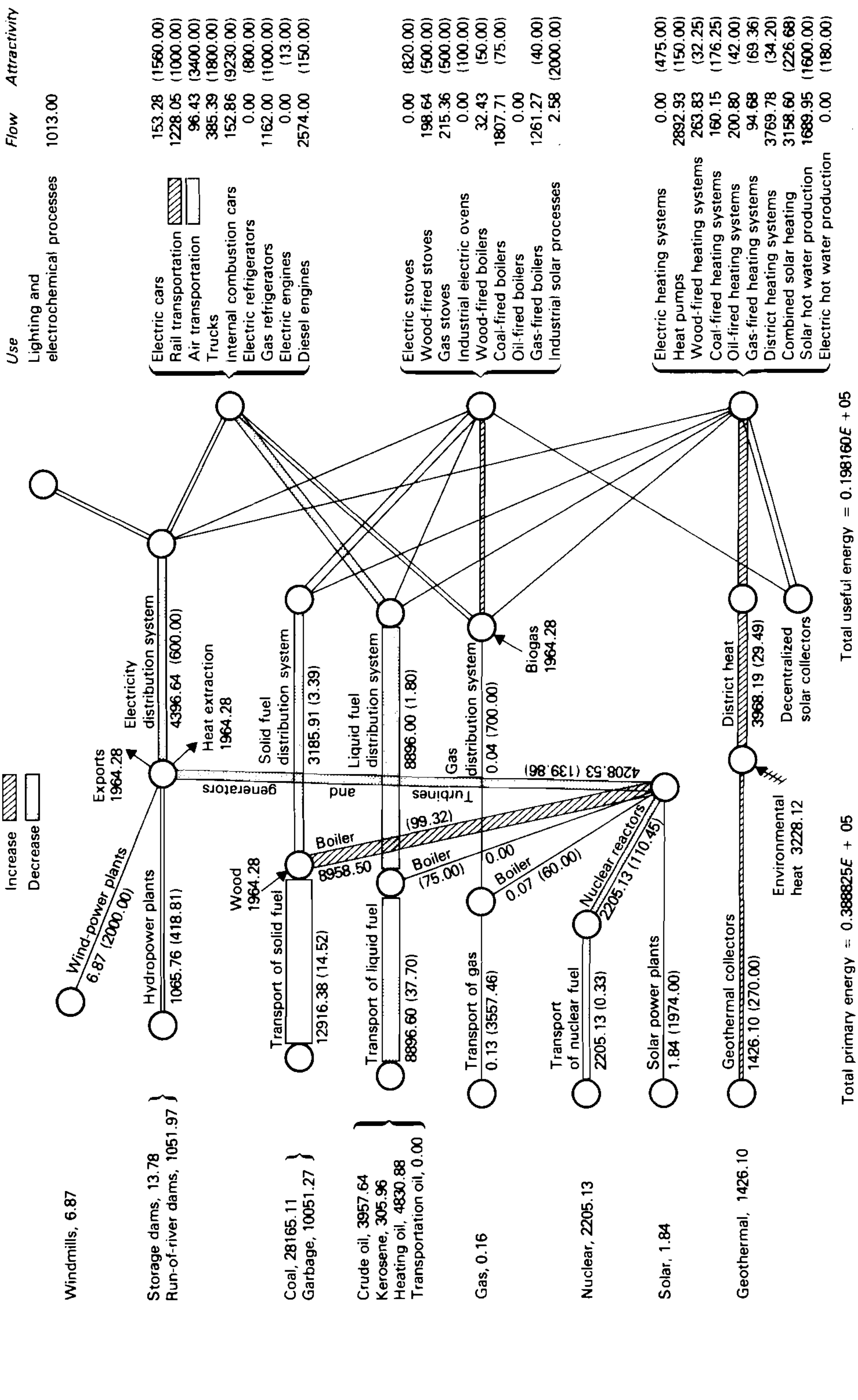
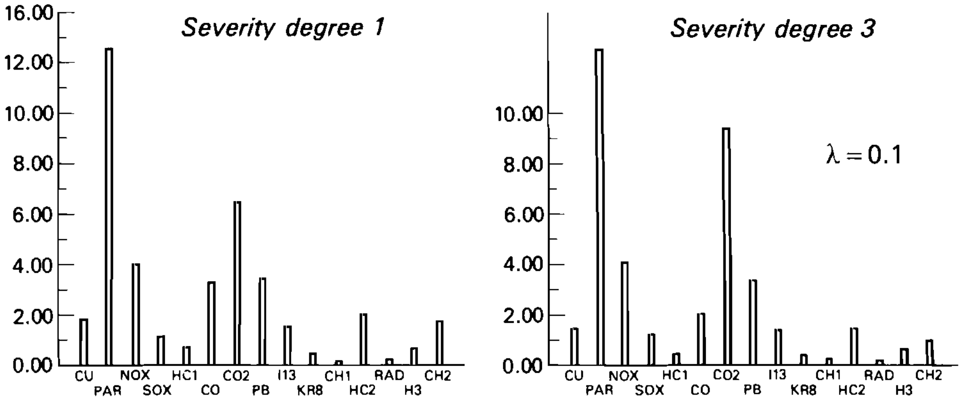


FIGURE 13 The energy-flow system for the cost–environment case. Units of MW are used throughout.



Emission

CU	copper	I13	iodine-131
PAR	particulate matter	KR8	krypton-85
NOX	nitrogen oxides	CH1	waste heat (1)
SOX	sulfur oxides	HC2	hydrocarbons (2)
HC1	hydrocarbons (1)	RAD	radon
CO	carbon monoxide	H3	tritium
CO2	carbon dioxide	CH2	waste heat (2)
PB	lead		

FIGURE 14 The total cost and principal emissions for the cost–environment case.

may be won or lost over the environmentalist stance. There is little consolation in the fact that the large majority of the scientific community considers their views on alternatives (decentralized solar, other renewable sources, conservation, simpler life-styles) to be unrealistic or expensive, or both.

This all suggests that any energy model approach should be flexible on policy options, making them explicit and identifiable. A scenario in which, for example, subsidies on certain energy investments are simply introduced by changing the parameters of the respective investment functions clearly does not satisfy such a requirement; more correctly, subsidies should enter at the level of budget allocation, i.e. at the point where the decision between alternative uses is actually made. The model presented in this paper is designed in such a fashion. At present, we still have little experience of the interplay of the major model elements. Nevertheless, we hope that it will accurately reflect the effects of scenario decisions on the overall behavior of the technoeconomic system.

REFERENCES

Becker, P., Codoni, R. and Staub, P. (1977). An energy-oriented input–output model: pilot study for the FRG. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.

Codoni, R. and Kirchgässner, G. (1978). Langfristiger Kapitalbedarf alternativer Energietechnologien. Konjunktur, 41(7): 16–26.

Energy Modeling Forum (Stanford University) (1977). Energy and the Economy, Vols. 1, 2. Stanford University, Stanford, California.
EPFL–IPEN–Projet d'Ecole Energie (1979). Banque de données CARTEN: caratéristiques des technologies énergétiques. Institut de Production d'Energie, EPF Lausanne, Projet d'Ecole Energie, Lausanne, Switzerland.
Hogan, W.P. (1979). An appraisal (of the economic–technical modeling program on long-term energy themes and related capital requirements). Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.
Kappel, R. (1980). Energietechnologien, Kapitalbedarf und gesamtwirtschaftliche Entwicklung: Ein Simulationmodell für die Bundesrepublik Deutschland. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.
Kirchgässner, G. (1979a). Systeme von Konsum–Nachfrage Funktionen. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.
Kirchgässner, G. (1979b). Investition, Kapitalstock und erwarteter Output in den 16 Nicht-Energie Sektoren des Zencap-Modells. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.
Kirchgässner, G. (1980). Systeme von Konsum–Nachfrage Funktionen: Empirische Resultate. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.
Manne, A., Richels, R., and Weyant, J. (1979). Energy policy modeling; a survey. Operations Research, 27(1): 1–36.
Reifman, A. (1978). The nature of the energy problem – perception and reality. Document 78-1015 (May 22). Congressional Research Service and Library of Congress, Washington, D.C.
Ruths, G.W. (1980). Investitions, Input und Zeitbedarf alternativer Energietechnologien. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich, Switzerland.
Saugy, B. (1979). Evaluation de stratégies énergétiques dans le contexte economique. Ingénieurs et Architectes Suisse, Bulletin Technique de la Suisse Romande, 105(2): 14–19.
Saugy, B., Bovet, Y., and Roulier, A. (1977). Modélisation du système énergétique suisse. In Proceedings of the Symposium SIMULATION 77, Montreux, Switzerland, June 1977. Actapress, Zürich, Switzerland.
Staub, P. (1980). Verknüpfung von alternativen Energietechnologien und gesamtwirtschaftlicher Entwicklung: Modell INTERFACE. Mimeograph. Center for Economic Research, ETH Zentrum, Zürich. Switzerland.
Toinet, J.-M. (1978). Grey energy: the generation of consumption in an input–output approach. Paper presented at IIASA Conference on Global Modeling, 6th, October 1978. (Also mimeograph, Institut de Production d'Energie, Lausanne, Switzerland.)

DISCUSSION

Brandvold *wondered about the assumption that investment in the energy sector has, in the model, such priority that it is always considered to be satisfied.* Codoni *agreed that investment in all other sectors is given as the difference between total investment and energy investment but this is in line with the economic policy of many European countries where energy has a definitely privileged access to the capital market. There are, however, checks in the model capacity to ensure that this assumption does not become too artificial.*

Mula *asked whether the data used for technological developments are based on past engineering experience.* Staub *and* Codoni *replied that, wherever possible, actual data were used; in some cases reasonable analogies had to be drawn, proceeding from engineering data to economic data, i.e. from a construction schedule to a payments schedule.*

Parker *asked how the model represents the switching of certain industries from one fuel type to another (e.g. the cement industry from coal to oil and then back to coal).*

Codoni *replied that the customary approach was applied, using econometric estimates of elasticities of demand and elasticities of substitution, as in most other similar studies.*

Asked by Mula *whether solid waste (e.g. in connection with the extraction of primary resources) was also considered,* Saugy *clarified that "emission" in the model relates only to emissions into air, water, and soil.* Roberts *asked whether the concept used of "environmental cost" included only the direct cost associated with repairing damage, or was it being used in a wider sense. In reply* Saugy *expressed the view that it is nearly impossible to assess in cost terms, for instance, an increase in atmospheric* CO_2. Roberts *stressed that it would be more than misleading to leave out such "costs", e.g. in the case of a nuclear option the risk associated with various kinds of subversive terrorist groups acquiring plutonium or other radioactive material in order to carry out blackmail, or their causing actual damage by blowing up installations with consequent loss of life.* Saugy *replied that such problems can be considered in the model without converting them into cost terms, for example, by generating two strategies with different weights attributed to that type of problem.*

Resources

EXPLORING THE INTERACTION OF THE ECONOMIC, THE ENVIRONMENTAL, AND THE INSTITUTIONAL DIMENSIONS

David Norse*
Interfutures Project, Organization for Economic Cooperation and Development, 2 rue André Pascal, Paris (France)

1 INTRODUCTION

I will interpret the conference title literally and will direct my comments largely to global models rather than to more complex regional or national models, and I will use the word "environment" in its broadest sense to include institutional aspects.

The International Institute for Applied Systems Analysis (IIASA) was established to further the development of systems analysis as an aid to policy formulation and selection. I will therefore assume that we are not here to consider the modeling of environmental problems from an academic point of view but with the ultimate aim of assisting the policy maker or decision taker. Hence the modeler must take account of the value systems and institutional structures in which such people operate. These systems and structures tend to change relatively slowly. Politicians are generally more concerned about being popular, gaining election or reelection, and managing current crises than they are about the niceties of mathematical programming or making informed choices on behalf of future generations.

Whilst global models can contribute to a deeper understanding of the general structure and dynamics of the major economic and ecological systems they do not lend themselves to the examination of many of the specific questions that policy makers have to address. The same can be said of more detailed models of particular components of global economic and ecological systems such as commodity and whole-ecosystem models. For example, the International Biological Programme supported the construction of very complex simulation models of whole ecosystems. By and large these models have not made a significant contribution to the resolution of specific environmental management questions (Watt, 1975). Models have to be specifically designed to address such questions, and global models have only a limited role to play in this domain.

---

* Present address: Central Directorate on Environmental Pollution, Department of the Environment, Marsham Street, London SW1, UK.

Nonetheless, global models have at least two contributions to make. One is in providing the global framework for partial models with a more restricted focus. It is not essential for such models to interface directly, and the link may be through mechanical iterations. The second type of contribution is the exploration of current or potential trends affecting the environment. Whilst the results may be too broad for specific policy recommendations they can contribute to the formulation of overall strategy.

This brings me to the underlying theme of my presentation, namely simplification in both the aims of and the approach to the introduction of environmental aspects into global models.

My presentation will be in four parts. First, I give a brief overview of the environmental problems that are likely to intensify or arise over the next two decades. The solution of these problems will require the combined efforts of economists and ecologists, both at the research and operational level and in gaining the necessary public and political support. Second, I attempt to place these problems in some order of priority by considering spatial and temporal criteria as well as order-of-magnitude effects. I then examine the interaction of the economic, ecological, and institutional dimensions of these problems. Finally, I make a few suggestions as to how global models may be used to explore some of the complex interactions that cannot be meaningfully investigated in isolation and the possible outcome of policies which could address these problems.

2 THE NEXT 20 YEARS

These will be different from the 1960s and early 1970s which provide the data base for the parameter values, etc., of many global models. This is a somewhat banal statement in that the world never stays still, so I will be more specific.

The growth patterns of the 1960s were characterized by low or declining energy and raw-materials prices, expanding populations in both the "North" and the "South", rapid increases in productivity in many countries linked to rising real wages, spin-off from military investment, falling tariff barriers to trade, etc. Consequently economic growth rates were generally high and inflation was relatively low both in OECD countries and in the Third World.

The probable pattern for the 1980s and possibly for the 1990s is quite different. Energy and raw-materials prices will be rising rather than falling, although for minerals perhaps not as rapidly as some studies suggest. Population growth in most Northern countries will be low or almost static and fortunately in the South fertility rates will be declining in most countries. Productivity growth will be heterogenous across countries and sectors but the general picture is expected to be one of slower gains than in the 1960s. In the North this will be a reflection of the limited attempts at structural adjustment, the low levels of research and development expenditure, and poor investment during the 1970s. These are partly the response to and partly the cause of high levels of inflation, limited wage flexibility, and uncertainty about energy prices and supplies, access to markets, etc. Such constraints are unlikely to be spirited away in the 1980s. In the South, particularly in the non oil-producing countries, many of these constraints will also prevail. Thus the lack of investment, energy prices and the balance-of-payments problems which they create, difficulties over access to markets, etc., will all undermine growth.

These changes will have a major impact on both the quantitative and to some extent the qualitative nature of the environmental problems that we may wish to examine with the aid of global models. Furthermore, in OECD countries in particular, they may imply a weakening in the public support for tighter environmental-protection regulations because people are generally unaware of their importance in the longer term and the costs seem to be too high for the short-term benefits.

In order to see how these changes may influence our thinking about which environmental problems to model I will present a brief sector-by-sector survey.

2.1 Industry

Changing patterns of demand and both qualitative and quantitative differences in international trade will have important effects on the structure of industry in both the North and the South.

In the North these changes will generally take place in the context of slow or moderate economic growth and will result in the relative but generally not absolute decline of certain industrial sectors (e.g. food processing and steel) which are currently either directly or indirectly the cause of pollution problems. The sectors showing the highest growth rates will be chemicals, mechanical engineering, and electrical engineering. Whilst increasing technological sophistication in the nature of these industries will involve a reduction in the energy and raw-material intensity of the goods produced, they are likely to cause greater micropollutant problems, which are commonly not easy to control.

Rapid industrial growth in the Third World, partly aided by the redeployment of polluting industries from OECD countries, in the context of weak regulatory activities will lead to a major increase in the emissions of conventional pollutants (SO_2, oxidizable substances, suspended solids, etc.). Over the next two decades they are likely to rise by a factor of three or four, compared with an increase of 50–100% in developed countries.

2.2 Agriculture

Production for domestic consumption in OECD countries will continue to level off and in most countries may be growing at less than 1% per year in the 1990s. The great uncertainty is the proportion of the demand of the centrally planned economies and the Third World which may be supplied by OECD countries. If this proportion is high, major increases in agricultural pollution are likely to occur in some countries, particularly through soil erosion, soil compaction, and fertilizer runoff.

Three particular problems come to mind which are very sensitive to this uncertainty. The first is that even with modest growth rates of production there will be increasing difficulties from non point-source pollution which is difficult to monitor, model, and control. The second is the continuing switch from extensive to intensive livestock production. Although this switch has been exaggerated to a degree by artificially high price levels for both dairy and beef products in North America and Western Europe it will no doubt continue in the medium term even if new price- or income-support policies are eventually adopted to remove such distortions. These intensive livestock units are a major source of solid wastes in drainage channels and rivers because of inadequate pretreatment and are commonly a much more serious cause of eutrophication than are inorganic fertilizers. The final problem concerns pesticides. It is not the problem of pesticide residues in the environment and their accumulation through food chains, which now seems much less of a danger than it did a few years ago, but that of insecticide resistance. Over 230 agricultural pests have become resistant to one or more of nine of the eleven major groups of pesticide. The time for resistance to appear after the first introduction of a pesticide group has fallen from about fourteen to six years. The rate of introduction of new insecticides has declined for the past ten years. Extrapolation of these trends signals serious possible dangers in the not-too-distant future.

Hopefully agricultural production in the Third World will expand at close to or greater than 3% per year. Such a growth rate does not carry with it serious dangers of fertilizer or livestock waste pollution at the aggregate level but pesticide problems could be similar to those of the developed countries. The most serious problems are likely to be those of soil erosion, desertification, deforestation, and salinization. The magnitude of these problems will continue to be sensitive to institutional changes, and I will come back to this point later.

2.3 Energy

In most countries energy generation is one of the major causes of pollution. Its share of SO_2, CO, CO_2, NO_x, and dust discharges is greater than that of any other human activity. Future levels of pollution from these emissions are highly dependent on changes in the level and pattern of energy supply and demand. Although the evolution of energy prices, of energy demand, and of the gains from energy conservation cannot be predicted with any certainty, reasonable estimates can be made for our purposes.

Consumption in the developed countries is likely to be almost double the current level and that of the Third World may increase by a factor of five or more. Unless the developed countries accelerate the development of non-fossil-fuel energy and introduce vigorous conservation policies, 70–80% of energy demand will have to come from coal or oil. In the Third World much of the energy demand will continue to be met by fuel wood, but with a rapidly rising share for oil and coal.

Thus over the next two decades gaseous emissions could increase by over 75% in the developed countries and by a factor of more than four in the developing countries. Expansion of electricity generation – whether it be fossil fueled or nuclear fueled – will require large areas of land for transmission lines etc. and will further disfigure the landscape. In the United States alone, some one million hectares of land will be required for transmission lines over the next 20 years. Opponents of nuclear power have stressed the risks from radioactive emissions but nuclear power also carries with it a major thermal pollution hazard to river and marine ecosystems if cooling water is discharged into natural water bodies. Increasing pressure on fuel-wood resources in many developing countries will continue to contribute to desertification in arid and semiarid areas and to deforestation and soil erosion in more humid areas.

2.4 Urbanization and Urban Problems

To a substantial degree the pollution problems considered in the review of industrial and energy prospects also belong here. Three other problems stand out significantly: the loss of agricultural land to urban and periurban development, urban waste disposal, and urban transportation. All three present major environmental dangers for the developed and developing countries.

Whilst increases in yields per hectare in developed countries have made it possible to reduce the area of arable land required for a given self-sufficiency level, this cannot be guaranteed for the future. A natural or man-made change in climate (e.g. via CO_2 emissions) could lead to less favorable conditions for agricultural production. Extremely rapid urbanization is occurring throughout the Third World and, given current policies, is likely to continue for the next 20 years and beyond. For historical reasons much of this urbanization is taking place in river valleys and coastal plains where the best arable soils are to be found. Agricultural productivity growth is very low in many of these countries, which, moreover, have no or only limited land resources left to develop. Thus they may be unable to compensate for the loss of arable land. It follows that it is vital to end this environmental destruction in both developed and developing countries.

One could continue with this sector survey since the growth of tourism is causing serious damage to mountain and shoreline ecosystems, etc., mineral extraction threatens land resources, and so on, but the examples given demonstrate clearly that there are many long-term environmental problems that could be explored using computer models. The central question is: Which are most appropriate for global models?

3 PRIORITY PROBLEMS

The problems outlined in Section 2 vary greatly in their ecological complexity, geographic distribution, degree of reversibility, and economic importance. Furthermore, they exhibit wide variations in their time constants. It is commonly difficult to appreciate the full implications of these time constants without recourse to a model which can indicate some of the linkage and multiplier effects.

This section will focus largely on those environmental problems created by or affecting agriculture rather than trying to cover the whole range of industrial and urban problems. Emphasis is placed on those environmental aspects which I consider to be most relevant to IIASA research activities, particularly the Food and Agriculture and the Resources and the Environment programs.

There is wide diversity of opinion as to which are the critical environmental problems for the future. The Global 2000 project in the United States talks about the severe degradation, if not collapse, of certain ecosystems and the loss of half the world's exploitable timber resources by the year 2000. The United Nations Environment Program (UNEP, 1977) and the Food and Agricultural Organization (FAO, 1978) have stressed the possibility that if present trends continue almost one-third of the world's agricultural land may be lost through desertification by 2000 (although much of this land is already very marginal). Kovda (1974) has highlighted the loss of irrigated land through salinization and waterlogging: namely about 200,000–300,000 hectare per year at the global level.

TABLE 1 Environmental problems relating to agriculture.

Irrigation and water management	Conversion
Salinization	Loss of genetic resources
Waterlogging	Loss of natural habitats
Lowering of water tables	Loss of agricultural land to urban and industrial development
Water-borne diseases	
Watershed management	Pollution from outside agriculture
Loss of water control	Air pollutants from urban and industrial activities
Water erosion of soil	Toxic chemicals in mine drainage, urban wastes, etc.
Siltation of reservoirs	Agricultural emissions
Soil Management	Fertilizer runoff and leachates
Wind erosion of soil	Livestock wastes
Desertification	Eutrophication in general
Soil oxidation	Nitrogen contamination of public water supplies
Soil compaction	Pesticide contamination of surface water and public water supplies
Soil fertility loss	
Pest management	Climatic perturbations
Pest and weed attack	Impact of agricultural activities
Pesticide resistance	Impact of nonagricultural activities

The participants in an IIASA Workshop in April 1977 identified 26 environmental problems which could be considered for inclusion in global or national agricultural models (Table 1). The list is a useful starting point for the present discussion. All the problems in the list are of some economic importance and most are affected by institutional factors, but not all of them can be meaningfully introduced into global models. The loss of genetic resources or natural habitats carries certain intangible costs but they are unlikely to be significant given the 20–30-year time horizon and level of aggregation of the IIASA agricultural models.

I propose three criteria for selecting the problems to be analyzed: namely economic importance, degree of reversibility, and, related to the latter, importance with regard to the sustainability of agroecosystems.

The first criterion, namely economic importance, is probably the closest that one can get to a general rule at the present time. I agree with the statement that "properly used, economic calculus is the most effective policeman of all in the fight to preserve the environment" (FAO, 1978) because most policy decisions in this area are currently taken by bureaucrats with an economics background. However, this is easier said than done, particularly when the incremental damage is small in the short term, even though it may be substantial in the longer term. The difficulty arises because the discount rate of the market and of most politicians is commonly too high to gain the correct responses. It follows that prices must enter into the calculation of natural-resource use in global models in order to indicate the possible range of the long-term costs of sustained environmental degradation.

When one examines Table 1 utilizing the second criterion, many of the problems are seen to be irreversible at least in the short to medium term, and in the long term reversible only at substantial economic cost. Thus the loss of land in Pakistan by salinization, the lowering of the water table in Texas, and the deterioration in irrigation-water quality in

Australia all fall into this category. Soil erosion and the loss of arable land to urban and industrial development also belong here. If desertification and deforestation result in the loss of the topsoil they are also essentially irreversible, and even where topsoil remains it will be impossible to reestablish the original flora and fauna.

Finally, there is the question of the sustainability of agroecosystems. Here the time constants are commonly very long and the complexity of the relationships very great. Thus the loss of phosphate fertilizer is generally caused by surface runoff and water erosion of soil and leads to eutrophication of rivers and lakes. Phosphate is essential for all growth processes. Consequently such losses cannot be sustained indefinitely; however, the world's phosphate resources are possibly adequate for a further 200 years at current rates of exploitation, although costs will rise substantially. It is therefore possible that the environment's ability to receive an increasing phosphate load in surface water may be reached before the mineral-depletion effect becomes pronounced. Furthermore, enhanced sustainability may follow from steps to reduce soil erosion rather than from the reduction of phosphate-fertilizer applications; this complicates the introduction of such problems into simulation models.

A more pressing problem is that of pesticide resistance, which was described in Section 2.2. Pesticide resistance is irreversible, and if it appears widely against all the major groups of insecticides the sustainability of many of the current agroecosystems will be undermined. Possible real-world responses include greater stress on integrated pest control, the improvement of resistance or tolerance in plant varieties, the introduction of mixed cropping techniques, and the extension of the area under cultivation. Not all these responses can be adequately simulated in highly aggregated models.

It becomes apparent that the choice of problems to be modeled depends to a substantial degree on the central aim of the global modeling exercise. If the aim is to build a series of relatively simple national models and to link them together to represent the world economy in order to examine global issues then there is little to be gained from introducing some of the problems in Table 1. Some of them have relatively limited international dimensions (e.g. water-borne diseases in Egypt and Mali) and if they are introduced, this should be done simply. However, if the intention is to build a global model that can be interfaced with a relatively complex national model in order to try and understand how domestic environmental problems affect or are affected by a country's international linkages then a greater degree of complexity becomes justified. Such national models may be produced in isolation from the global model provided that they are designed with interface difficulties in mind. Alternatively, where the global model is essentially a number of simple national or regional models linked together, these can be the starting point for the development of more complex models. In either case the results of such two-tier models are more likely to be considered by policy makers because they can identify more clearly both the structure and the problems of their own country.

4 EXPLORING THE INTERACTION BETWEEN THE ECONOMIC, ENVIRONMENTAL, AND INSTITUTIONAL DIMENSIONS

If initially one looks at the linkages between the economic and environmental dimensions one finds that some of the problems in Table 1 should be examined as an

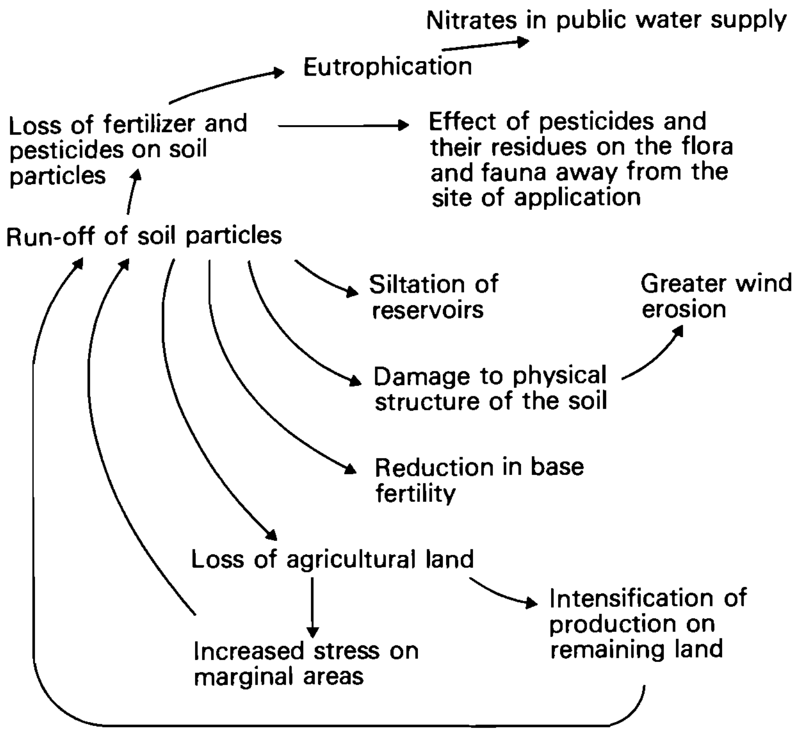


FIGURE 1 Links between soil loss by water erosion and other environmental problems.

interrelated group. Figure 1 illustrates the links between soil erosion and several other environmental problems which it causes or accentuates. It is possible to conceive of positive feedback loops that may reduce the level of soil loss (e.g. changes in cropping patterns, adoption of minimal cultivation techniques, and investment in improved drainage and flood control), but there are also negative feedback loops that can intensify the erosion (e.g. reduction in the fallow period and siltation of rivers and reservoirs). Most of these loops can be introduced into models.

However, it is possible to move "upstream" of these dimensions and to examine how institutional aspects interact with them. Figure 2 is a simplified representation of some of the institutional features which may influence soil erosion. The development strategy chosen by countries is of major significance here. When stress is placed on urban industrial development, capital is commonly extracted from agriculture and unfavorable farm-product prices are maintained to ensure low-priced food for the more politically volatile urban populations. Poor prices tend to lead to low employment creation in agriculture and the agroindustries, overcropping, and low fertilizer use. These in turn lead to increased cultivation of marginal soils, a reduction in soil organic content, and hence greater soil erosion. This chain of events tends to perpetuate a pattern of slow productivity gains in agriculture, with static or declining per capita output and increasing food-import requirements.

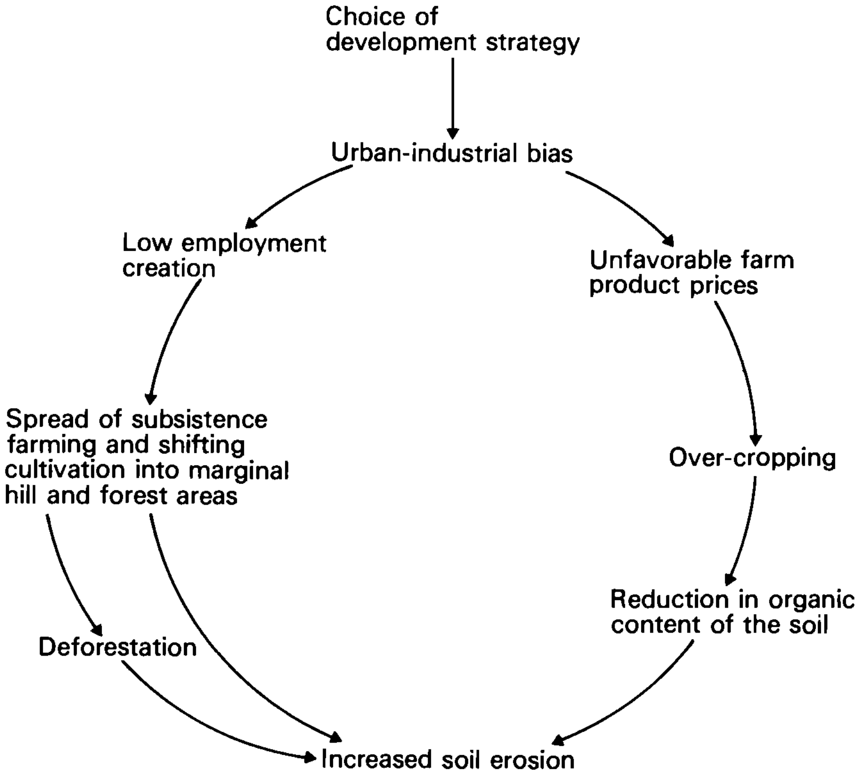


FIGURE 2 The institutional dimension of soil erosion.

When one considers the interaction of these three dimensions it becomes possible to introduce a further criterion for selecting the environmental problems that can be examined using global models. This is because technological and sociopolitical uncertainty interact strongly with the economic criteria.

Several consultants from the Third World who wrote papers for the Interfutures Project on the long-term prospects for their country or region thought that during the next ten years or more there would be no major change in the political power structures in certain developing countries and hence that the prevailing bias against agriculture would continue for some time. With such a bias agricultural output may grow at only 1–2% per year, as opposed to 3–4% per year with policies favorable to agriculture. In the countries with low growth rates there may be substantial increases in soil erosion and deforestation as poor farmers or the landless attempt to develop marginal land, whereas in the countries with high growth rates intensive agriculture is likely to introduce an additional set of problems (e.g. fertilizer and pesticide pollution). The results of most national and global models will be much more sensitive to uncertainty concerning such socioeconomic parameters than they are to environmental parameters.

Although the aim is not to predict the future, which is impossible, but only to explore the possible outcome of the continuation of a number of trends or breaks from them, technological uncertainty is still very important. It is not possible to predict technological breakthroughs but the evolution of certain environmental problems is very sensitive to technological change. In 1970 it would have been impossible to foresee the synthesis of photostable pyrethroid-based insecticides in 1973 or the rapid commercialization of this breakthrough (these insecticides were widely marketed within three years instead of the normal five to eight years) yet pyrethroid-based insecticides may play a major role in the reduction of pesticide pollution.

5 INTRODUCTION OF ENVIRONMENTAL ASPECTS IN GLOBAL MODELS

First of all, since the aim is to examine environmental problems from a policy point of view, we must consider who the decision maker is and to what extent his actions can be introduced into models. We are principally concerned with decisions taken at two levels, namely the farm and the national level.

In a sense the farmer is represented by the production function in which he varies the mix of inputs of fertilizer, pesticides, irrigation, and land to minimize costs or to maximize profits in the short term (see HMSO (1977) and de Hoogh et al. (1977) for descriptions of this type of function). Responses to the long-term costs of environmental damage can be introduced into such functions. For example, it is possible to adapt the approach used in the Systems Analysis Research Unit Model (SARUM) to simulate the behavior of farmers faced by risk and uncertainty concerning returns to fertilizer use (HMSO, 1977). The approach is basically the introduction of coefficients to increase or decrease the perceived price of the various production inputs relative to the market price in the model so as to lower or raise their use. It can also be used to simulate the actions of national decision makers (e.g. regarding investment decisions and emission standards).

The team which constructed the Model Of International Relations in Agriculture (MOIRA) were one of the first to endeavor to simulate the impact of national decisions concerning the choice of development strategy. They did so by introducing algorithms to cause changes in the terms of trade for agriculture relative to the rest of the economy and hence to examine some of the consequences of policies biased against agriculture. Such an approach can be useful in exploring some of the institutional aspects of environmental degradation.

The selection of specific environmental problems and their mode of introduction depends on the purpose of the models as previously discussed, on the availability of data and theory, and on the state of the art in modeling itself. Losses of genetic resources and natural habitats are ill-defined problems at the modeling level, and both the data and theoretical foundations are weak. Fertilizer leaching is better defined but our knowledge of humification and mineralization is inadequate. Hence it is difficult to determine the contribution of the various nitrogen sources to the observed concentrations in lakes and rivers. Even the micromodels (e.g. watershed models) incorporating these processes are not entirely satisfactory and thus there is little to be gained from incorporating them in global models.

For a number of problems the most effective approach may be to use theoretical or probability models as the first step and to introduce the results into global or national models without any actual interface between the two. Thus the emergence of pesticide resistance can be examined using theoretical models like those described by Comins (1977) and can then be introduced into global models as exogenously imposed shocks or long-term changes in the yield response. The damage function could be based on the losses which have been observed from widespread epidemics in recent years (e.g. corn blight in the United States, wheat rust in India, and tungro virus in the Philippines). A similar approach could be used for climatic perturbations, but combined with shifts in the stocks of land and the yield asymptotes.

Most of the other problems in Table 1 can be introduced directly into global models but, as stated earlier, some of them (e.g. water-borne diseases) will have little impact on the results of such highly aggregated models. Consequently I believe that they should be introduced in the simplest manner possible. Simplicity need not reduce explanatory power; in fact complexity often clouds the issues. The principle questions are: Is it necessary to model explicitly some of the feedback effects? And, where it is necessary, are nonlinear relationships needed? Land loss by waterlogging, soil erosion, and deforestation may enter as simple coefficients affecting land stocks, based on historic trends, or as a simple function of certain endogenously determined factors such as agricultural population density or the intensity of agricultural production.

When interactive feedback is required an effective point of entry is the agricultural production function. Fertilizer and pesticide runoff can be a linear function of the application rates determined by the production function. Salinization and irrigation-water quality may be related to water-extraction or irrigation-application rates and may involve linear or nonlinear feedback loops to the yield response. In reality salinization, for example, is much more complex than this simple representation. At the command-area level it would be necessary to take account of soil characteristics, microclimate and macroclimate, the crop type, investment in drainage, etc.; however, such a complex approach is beyond the current state of the art and is not very meaningful at the global level.

6 CONCLUSIONS

Modeling the problems in the manner proposed will help to identify the general nature, magnitude, and location of the stresses that man is placing on the environment. It will alert the policy maker to the main issues involved but thereafter it will require complementary studies exogenous to the global model to aid progress towards decisions on which of the available policy alternatives should be adopted.

There are diminishing returns to increasing the complexity of the representation of the economic or ecological systems in global models. There is little to be gained from progressing to the point where further refinements in either structure or dynamics add only a marginal benefit. Resources are far better spent on applying sensitivity analysis to less complex relationships.

REFERENCES

Comins, H.G. (1979). The control of adaptable pests. In G.A. Norton and C.S. Holling (Editors), Pest Management. IIASA Proceedings Series, Vol. 4. Pergamon Press, Oxford, pp. 217–225.

FAO (1978). The State of Food and Agriculture 1977. Food and Agriculture Organization of the United Nations, Rome.

HMSO (1977), SARUM 76 global modelling project. Departments of the Environment and Transport, Research Report 19. Her Majesty's Stationery Office, London.

de Hoogh, J., Keyzer, M.A., Linneman, H., and van Heemst, H.D.J. (1977). Food for a growing world population. In G. Bruckmann (Editor), MOIRA: Food and Agriculture Model. CP-77-1. International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 13–44.

Kovda, V.A. (1974). Biosphere, Soils, and their Utilization. Academy of Sciences of the USSR, Moscow.

UNEP (1977). Report of the United Nations Conference on Desertification. S/Conf. 74/36. United Nations Environment Program, Nairobi.

Watt, K.E.F. (1975). Critique and comparison of biome ecosystem modeling. In B.C. Patten (Editor), Systems Analysis and Simulation in Ecology, Vol. III. Academic Press, New York, pp. 139–156.

DISCUSSION

In reply to a question by Steger, Norse *said that most people have no idea what the long-term consequences of current policies may be. One of the main purposes of global modeling is to make these effects more tangible.* Steger *asked whether the model could give a rank order of these long-term problems, as to which ones would come up before which other ones, and in which order of magnitude.* Snower *added that such a rank order might turn out to be different for different parts of the globe.* Norse *continued his argument by adding that countries are foreclosing more and more options, for example, by urban sprawl over (potentially) arable land.* Robinson *added the example of narrowing of the gene pool through intensive cultivation of a few strains only.* Norse *replied that these are problems of different orders of magnitude: whereas "lost" gene strains could be (relatively easily) recovered through crossbreeding, the examples that he had mentioned are practically irreversible.*

Kellogg *asked to what extent governments feel responsible for long-term consequences, such as erosion or salinization, which intervene into farmers' practices, or to what extent do they (tacitly) assume that farmers themselves will know best what is good for them. Will a farmer not change to a different pesticide if he sees it is not working any more?* Norse *disagreed: often it is a problem that very slowly accumulates over time and therefore escapes the attention of the farmer. Nothing ensures that the farmer will "naturally" act in the way which is optimal (from the long-run point of view). The usefulness of models lies in the fact that they can show the decision maker what are the long-term implications of what he is doing. Decision makers may be either the farmers themselves or government personnel who exert influence on agriculture.*

Roberts *summarized the results of several presentations: it seems highly likely that man-made climatic changes might turn "corn belts" into deserts; if such processes could be incorporated into global models, in what way would it increase our knowledge?* Norse *replied that such an incorporation should prove particularly fruitful on a regional basis, exploring the consequences of climatic shifts in the main producing areas of the world. In a global model such changes of production could be linked with the trade matrices to yield a global picture.*

SOME QUESTIONS OF TASK PLANNING IN THE FIELD OF NATURE USE AND ENVIRONMENT PROTECTION

S.A. Pegov
Institute for Systems Studies, 29 Ryleyev Street, Moscow (USSR)

The present stage of human development is characterized by steady growth of the intensity, scope, and variety of human influence on nature. As a result of this process, on the one hand there is less direct exploitation of biological systems owing to the involvement of nonorganic natural resources in the economic turnover while on the other hand the introduction of nonconventional components into these systems increases the load on the biosphere.

It is becoming increasingly obvious that the "global capacity" of the biological systems which are the basis of human life is limited. Further satisfaction of growing human needs will therefore be possible only if there is a fundamental change in the forms of biosphere use. In the man–nature relationship human society acts in a framework of certain social institutions.

The socioeconomic aspect of environmental problems is a key factor: the problem should be considered together with its social background. The problem of environmental protection has specific features in every state, depending on the governing form of ownership of land and other means of production; it is therefore necessary to look for the solution to the problem at the national level.

The global environmental research conducted in the Soviet Union is methodologically based on the biosphere concept proposed by Academician V.I. Vernadskiy. The overall goal of the research is to provide a theoretical basis for the "ecologization" of all spheres of human activity including production and consumption and education and upbringing. The "ecologization" of practical human attitudes towards nature will lead to the transformation of the social sphere (i.e. human society and its technology) which will help to preserve the biosphere for the life of future generations. The transformation of the social sphere implies the adjustment of the regulating mechanisms of this system, which has so far developed spontaneously. To this end it is necessary to analyze the totality of environmental problems in connection with other global problems; this is impossible without elaborating integrated plans for economic development including natural-resource protection.

The structure of such plans must be based both on the structure of goals and decisions adopted by a society in the process of its development and on the structure of

MAN

Optimal relations between human society and nature		
Goals of state	Goals of branch	Goals of region
• Ensuring stable peace • High standard of living • Demographic - process control • Ensuring food supply • Reduction of dangerous disease • Ensuring high economic activity • Etc.	• Keeping industry supplied with resources • Creation of wasteless technology • Reduction of job-related disease • Ensuring effectiveness of industry • Etc.	• Migration process control • Complex utilization of ecosystems in economics of region • Observance of sanitary standards in region • Etc.

BIOSPHERE

Systems ecological problems		
Biogeographic problems	Integrated problems	Socioeconomic problems
• Violation of climate • Violation of biogeochemical cycles • Violation of soils • Ocean problems • Ecological monitoring • Etc.	• Anthropogenic influences • Complex appreciation of the state of the environment • Methods for forecasting ecosystem development • Ways of presenting ecological information for decision making • Etc.	• Influence of ideological concepts and social structures on the use of the environment • Significance of the environment in public production • Ecological problems of national utilization of natural resources • Significance of ecological education for individuals • Etc.

FIGURE 1 The man–biosphere system.

problems arising from the relationship between biosphere complexes and the socio-economic system of the human society (see Figure 1). We by no means claim to have given a complete and full tree of goals in the three-level diagram shown in the upper part of the figure. It could certainly be updated, and, specifically, some extra levels describing the human goals in more detail could be added; however, this would affect the clarity of the present diagram. Perhaps it would be reasonable to specify the second level as referring to some of the most general goals connected with the integrated use of natural resources and environment protection.

It seems natural to include goals reflecting the administrative and geographical structure of the socioeconomic system in the second level. The third level contains a number of research-program goals defining the range of practical tasks connected with the evolution of the biosphere or its components under anthropogenic influences.

In the lower part of Figure 1 we have compiled a tree of problems of systems ecology concerned with the interaction between the biosphere complexes and the human socioeconomic system.

As mentioned earlier, the problem tree is not complete. There seems to be no sphere of human activity which does not depend on the environment or may not somehow influence it. Therefore the second level includes mainly unified and generalized notions. Thus the section of natural-science problems includes research on both inland and ocean ecosystems, climate, etc.

It should be pointed out that the creation of information support for decision makers on the problem of the environment is universal and covers all the programs and tasks of the structure under review. This is not as easy as it may seem at first. Indeed the clear and compact presentation of the results of an analysis of a major ecological task or a program, together with a set of possible alternative strategies, is very important. It is a relatively sophisticated undertaking and requires an interdisciplinary systems approach.

The intersection of the goal and problem structures defines the system of the whole complex of practical tasks, the answers to which should be given by the research and development programs within the framework of the national development programs.

Thus the advantage of the suggested matrix structure is that it becomes possible to define clearly the range of questions and the officers responsible for the achievement of each goal.

The totality of tasks that arise in the interaction is defined by the objective contradictions raised by the dual character of the environment. On the one hand we consider the environment as man's habitat while on the other hand it is part of the economic system of human society. Thus in initiating any research in the field of nature use and environment protection we must consider the whole complicated socioecological system in the analysis of which we must simultaneously look for possible solutions.

In each case careful consideration of such a system will result in the definition of the structure of the problem investigated and the relationship between its elements. The structuralization of the problem makes it easier to understand. In the field of nature use and environment protection the problems refer to systems which are in a certain sense a totality of economic planning and management organizations and industrial and agricultural enterprises. The problems also cover the structure of land use, the totality of ecosystems, etc. (depending on the task). The totality of events as actions in the development of the society–environment relationship in time and space can also be presented as a system.

As a criterion for evaluating the state of the system we can use the concept of "correlation of impacts" in a certain time interval. This concept is supposed generally to reflect the correlation of society's major impacts on the biosphere and the latter's response; in a particular case it characterizes the relationship between natural systems and man in a certain region and situation. On the one hand this correlation is defined by the objective reasons connected with the system's specific characteristics and structure (e.g. development of the state and deterioration of ecosystems, etc.) and on the other hand this correlation can depend on subjective factors, particularly the views that are held on the use of nature.

In investigating the nature–society relationship it is necessary to take into consideration homeostasis, i.e. the state of the socioecological system that provides the conditions of its existence. In this connection we can speak about homeostatic limits and balance.

In the man–nature interaction the concept of homeostatic balance should be considered together with each of the interacting subsystems. Both human society and nature are in the process of constant interrelated development; it would therefore be wrong to study only the ecological balance or only the balance of an economic system.

Human society's anthropogenic influence changes natural systems and in the long run causes their deterioration. The rehabilitation of natural systems increasingly requires human effort, i.e. larger investments at the expense of societal development. This is because as a rule the rate of the ecological system's anthropogenic changes considerably exceeds that of the rehabilitation processes in the ecological systems. In other words nature cannot give a prompt response to the rapidly changing loads that are placed on it and society has to "help" it. There may be a moment in the process when society will not be able to invest still larger means in the rehabilitation of weak ecological systems. We think that the so-called "ecological crisis" is due to these very reasons, which stem from the dual nature of ecological systems as habitat and as a unit in the economic system.

The man–biosphere system does not simply seek to achieve the homeostatic balance typical of these dynamic systems. Other significant factors are the rate of the changes and the trajectory of the motion. In addition, we must look into the problem of how this or that effect can be reached and what resources will be required. All this is considered when the goals of the subsystems development are specified, which is generally done with the help of quantitative criteria.

One cannot say that the goal of development is defined clearly enough if it is formulated as, for instance, "to improve the setting" or "to achieve a better situation". In these cases only the desirable direction is indicated but a quantitative criterion of effectiveness is not applied. A quantitative criterion makes it possible to measure the goals and to relate them to the means of their achievement in analytical terms, the knowledge of which will facilitate solution of the problem. In this case the task will be reduced to finding a concrete mathematical description.

There is a variety of methods for achieving the objectives. They are dictated by the structure of the tasks in which the dynamics of natural resources must be considered in close connection with both socioeconomic processes and decision making.

The investigation of the processes occurring in various natural systems does not today present any particular theoretical problems. These processes have, as a rule, a strongly pronounced physical character and are governed by laws which were the object of study at earlier stages of the history of science. The enormous volumes of information accumulated by natural scientists permit one to use advanced formal methods successfully to model the natural processes and in many cases to reach concrete decisions describing the development of ecosystems. At the same time we often forget that in fact all the created models describe the so-called "clean environment", without taking into account its second role as a link in the economic structure of society. The consideration of some factors of anthropogenic influence does not solve the problem as a whole since under anthropogenic influence the basic objective laws of the processes in the ecosystem undergo changes. The main difficulty lies in the fact that the characteristic times of anthropogenic changes are as a rule shorter than the characteristic times of the processes in ecosystems. In other words the investigator has to deal with systems which have a constantly changing structure and linkage and which are therefore explained by various laws. This does not mean violation of the basic physical laws of the development of nature (e.g. the conservation of matter, energy, etc.) but it is necessary to formulate these laws for a newly created structure of the ecosystem under review. We can also state this in a purely mathematical way: it is necessary to consider a system of equations with constantly changing boundary conditions and coefficients.

Thus the change in the structure of the natural system is connected first of all with anthropogenic influences, which result from achievement of the goals of socioeconomic development. Therefore in order to create a system for forecasting the anthropogenic environment, which is actually the entire biosphere, it is necessary to develop methods of integrated evaluation of the state of the environment, taking into account anthropogenic influences. Serious attention should be given to the construction of the tree of the goals of the socioeconomic system in the process of the exploitation of ecosystems.

The application of expert judgments gives an opportunity to evaluate the relative importance of different elements in the tree of goals and to express their links quantitatively. Methods of transition from the tree of goals to network models and dynamic models are also well known.

Logicolinguistic models can also be used for studying the anthropogenic characteristics of the environment. In this case a scheme of the process under review is developed indicating the sequence of different stages which can be presented as a sequence of events involving the specified elements. The utilization of logicolinguistic models helps in the study of the main elements of the system and the links between them. The results are considered in matrix form or as a tree of goals showing the stages of the process, tasks, criteria, etc.

All these methods need expert judgment. The only difference is in the graphic form in which information is presented (tree of goals, matrix, diagram, etc.). This helps experts to express their opinion more precisely and soundly. Of course such methods of analysis of anthropogenic influences require a system for formalization of the main events and decisions in the relationship between society and nature.

The development of a methodology for integrated evaluation of the state of the environment, taking into account all aspects of the relations between ecosystems and socioeconomic systems, is at present a necessity in the research on development processes.

Other Modeling Work

A PRELIMINARY MODEL OF CONFLICT AND COOPERATION IN FOREIGN-POLICY BEHAVIOR*

Michael Don Ward
International Institute for Comparative Social Research, Science Center Berlin, Steinplatz 2, D-1000 Berlin (West)

1 LITERATURE REVIEW

Both theoretically and empirically most attempts to understand the foreign-policy behaviors of post-1945 nations, especially the United States and the Soviet Union, have been driven by the underlying rationale which posits international relations to consist primarily of conflict: conflict and conflict resolution stand at the core of the last 30 years of scholarship in international relations. Given the salience (i.e. deadliness) of international military conflict, it is understandable that post-World War II scholarship on international politics has been dominated by the politics-as-conflict paradigm. Decidedly this era has a history marked by confrontation and conflict, especially among the major powers. As superpower leaders of aligned blocs of nations, the Soviet Union and the United States are typically viewed as global adversaries whose goals are inherently conflictual. This perspective is summarized by Taylor (1978) who notes:

> "The contribution of the realists' beliefs about the lack of harmony of interest in the world and about man's capacity for evil and his thirst for power is, therefore, to reinforce the system argument: not only do states not have protection, they are also in danger and so need it. This viewpoint emphasizes international relations theory as basically conflictful. It leads to the opinion that states should place minimum reliance on the words of others and should be constantly alert for threats or potential threats . . . states should prepare to deal with the worst possible situation. They should guard against the capabilities of others rather than the intentions. *Cooperation is possible*, but only when it serves the national interest defined in terms of power." (Taylor, 1978, p. 130)

There are of course some notable exceptions to this paradigm. Regional integration theory may be seen as an attempt to understand (and in some cases model) organizational and functional cooperation among international entities which possess goals that are at

* A revised version of this paper appears in International Studies Quarterly, volume 26, number 1, 1982.

once conflicting and cooperative. Negotiation and bargaining theories also incorporate cooperative solutions to situations which are modeled as inherently conflictual, typically via two-person, zero-sum game theory. (Zartman (1977) gives an overview of sociological and psychological work in this area. Schlenker and Goldman (1978) discuss cooperators and competitors in experimental conflict situations. See also the work of Druckman (1977).) Yet, even within these perspectives, especially the latter, the role of conflict behavior is dominant. Further, the oft-repeated saw about the dimensionality of conflict and cooperation still permeates many studies: cooperation is often viewed either as the absence of conflict or as its opposite, in spite of the theoretical and empirical arguments to the contrary (to be discussed later). However, it seems undeniable that the foreign-policy behavior of major international actors simultaneously includes both conflict and cooperation. Complex foreign-policy situations exhibit conflictual and cooperative behaviors, intermixed in strategies for pursuing single and/or multifaceted goals. Therefore models which focus solely on conflict to understand the range and mix of international foreign-policy behaviors are falsely partitioned (Ashley, 1979) and are likely to lead to erroneous statistical inferences, inaccurate substantive conclusions, and inadequate policy recommendations.

The diplomatic history of the past decade shows much evidence of the role of cooperation in the foreign-policy behaviors of both major and minor powers. For example, the Strategic Arms Limitation Treaty (SALT) and Mutual and Balanced Force Reductions (MBFR) negotiations may each be viewed as residual effects of détente, defined not only in terms of reduced hostility between the Soviet Union and the United States but also in terms of increased joint cooperation and friendliness. The rapprochement of the People's Republic of China and the United States may also be offered as evidence of the importance of major-power cooperation. At first sight, it would appear that major-power cooperation may be returning to a dynamic period (much like that which existed in the 19th century) from the potent dormancy imposed by the rigidity of the cold-war politics of the 1950s and early 1960s. The increased politicization of the Third and Fourth Worlds with respect to a new international order in the 1970s has also underscored the relevance of both minor- and major-power cooperation (Jervis, 1978), as demonstrated, for example, in the cooperation of oil producers in imposing price increases on western purchasers of petroleum. Despite the salience of including both cooperation and conflict in the frameworks with which foreign policy is studied and monitored there is a relative paucity of literature which addresses this point. Beyond studies on conflict behavior per se, several major themes run through the scholarly and policy writings on foreign-policy behaviour. Each deals with the questions of whether conflict and cooperation are separate or related, competing or complementary processes.

In much of this literature the underlying perspective is one of investigating the hypothesized linkage which exists between conflict and tension and between tension and violence (and war). Klingberg (1952) was perhaps the first scholar to utilize psychological scaling techniques to measure the belief sets of, and friendliness and hostility in, the international system. The early work of Holsti (1963) focused this investigation of international tension on a content-analytic technique. Another early effort was the work of Gamson and Modigliani (1971). Goldmann has been one of the most creative researchers developing empirical and theoretical techniques to track the level of East–West tension in the perceptions of European elites (Goldmann, 1972, 1973, 1974; Goldmann and

Lagerkranz, 1977). The tension variable which serves as the focus of his work is composed of both conflictual and cooperative components (favorable and unfavorable conflict-analytic units); however, the discussion of the international climate (tension) does not disaggregate these separate components, nor does it highlight the salience of each. Mahoney (1977) has utilized the Goldmann tension data to study public (mass) opinion and defense expenditures and Rattinger (1975) has attempted to incorporate tension data into bureaucratic-decision models of defense expenditures. In each of these studies conflict and cooperation are largely treated as reciprocal phenomena: knowledge of one would permit mathematical (and presumably theoretical) derivation of the other (other studies in this area include Boulding (1963), Holsti (1963), Calhoun (1971), Bobrow et al. (1973), and Hart (1974)). Nowhere is this assumption quite so clear as in the non-empirical simulation of conflict and cooperation constructed by Ruloff (1975) in which cooperation is conceptualized as the movement towards reduced levels of conflict which are generated through adaptive-expectation mechanisms.

However, in their survey of the literature on international relations Alker and Bock (1972, p. 449ff.) noted that "almost all scholars would agree that cooperation and conflict are both present in the mixed-interest situations and payoffs of international relations." Rummel (1971) has also argued for the existence of such simultaneous conflict and cooperation behaviors. Even within this perspective it is still possible to maintain that conflict and cooperation are independent behaviors which may be, for example, orthogonal (à la Rummel) to one another (see Alker and Bock, 1972, pp. 449, 450).

The specific interrelationship between a nation's conflict behavior and its cooperation behavior is often argued to be indirect. This is largely a result of the ways in which foreign-policy behavior has been studied rather than a consequence of specific findings. In particular, conflict and cooperation are often argued to be related only insofar as they are separately affected by other influences (Rummel, 1971; Sigler, 1971; Park and Ward, 1979; and East and Gregg, 1967; inter alios). Others have argued, either explicitly or implicitly, that they are either opposite ends of the same continuum or are orthogonal (inter alios, Boulding, 1963; Rummel, 1971; Bobrow et al., 1973; and Kegley, 1973). There has been little work which has sought to identify the explicit relationships which may exist between conflict and cooperation.

This leads to a second theme: conflict and cooperation are not only simultaneously present in the foreign-policy behaviors of a wide range of international actors but they are also statistically related to one another in a strong positive fashion. Of all the findings in the literature this one is clearly the most consistent and for many of the writers the most perplexing. The earliest evidence of the statistical relationship between conflict and cooperation is found in the pioneering work of Cattell (1949). The basic strong positive relationship has been replicated in a variety of independent research undertaken subsequently (East and Gregg, 1967; Russett, 1967; McClelland and Hoggard, 1969; Soroos, 1977; Robertson, 1978; and Park and Ward, 1979).

Although the first and second theme appear to have contending interpretations it is possible to integrate them without contradiction. Any single event, in and of itself, may in fact be either conflictual or cooperative. In actuality this is how events-data coding schemes typically are constructed and applied. Thus, at the level of the individual event, perhaps conflict and cooperation are reflexive in the sense that the presence of one type of behavior implies the absence of the other. However, individual events are rarely initiated outside of a much larger international context. They are part of a stream of interactions among international actors. This stream includes both conflict and cooperation. At this level conflict and cooperation do not appear to be exclusive behavioral modes. (For Rummel (1971) they are orthogonal and correlated because they have "similar" projections on the behavior space of foreign policy.)

A third thread that runs through much of the scholarly writing is that, as far as present models are developed, cooperation is considerably more statistically patterned than conflict. Several research endeavors justifiably lay claim to the parentage of contemporary empirical scholarship on international conflict and cooperation patterns. (Notably, North et al. (1963) applied content-analysis techniques embodied in the computer program known as the General Inquirer to diplomatic documents from the pre-World War I crisis period, Rummel (1966) developed an event-coding scheme for the New York Times, and McClelland and associates developed a diplomatic-history framework into a similar coding scheme known as the World Event Interaction Survey (WEIS).) One of the earliest reports from the WEIS was a factor analysis of 1966 WEIS data for 83 polities reported by McClelland and Hoggard (1969); this revealed that more than one-half (55.8%) of the total variance in international events was explained by a single factor which was labeled "cooperation and collaboration". The study largely ignored this finding, focusing instead on the other, conflictual, patterns in the data. McClelland and Hoggard asserted that the cooperation and collaboration structure was one which indexed routine international behavior and which presumably was better understood and less intriguing than "nonroutine" conflict interactions. Rummel (1971), in his formulation of the concatenation of status theory and field theory, devotes considerable attention to the derivation of the proposition that dyadic cooperation occurs with greatest frequency among nations of relatively equal power status and economic development. In contrast, conflict is more frequent where the attribute differences in status and development are greatest. In his 1972 study of these propositions with respect to US foreign relations Rummel identifies clusters of Western European and Anglo-American cooperation which, in line with the foregoing argument, are found to be statistically related to power parity, differences in economic development levels, and political similarity (Rummel, 1972). In this field-theory tradition, various scholars have examined these ideas in a larger spatial–temporal domain and with respect to another nation's (China's) foreign policies and have obtained results which tend to corroborate Rummel's findings. In researches in different contexts East and Gregg (1967) report a higher variance explained for cooperation vis-à-vis conflict. (Issue-specific work on petroleum-related foreign-policy behaviors has found the contrary: in general, conflict is more patterned than cooperation though there is considerable evidence that this pattern itself varies across different countries and time frames (Park and Ward, 1979).) Robertson (1978) and Hybel and Robertson (1978) have also examined patterns of conflict and cooperation, finding cooperation between the United States and the Soviet Union more highly patterned than conflict. It tends to be the case that cooperation is highly reciprocated.

However, many scholars have questioned the conceptual and methodological underpinnings of examination of international cooperation. Eckhardt and Azar (1978) have conducted a major empirical survey of international cooperations, using the events data of the Conflict and Peace Data Bank (COPDAB) (Azar and Sloan, 1975). They assert, in contradiction to much of the empirical and theoretical underpinnings of the interrelationship of international conflict and cooperation, that the conceptualization and measurement of cooperation are each sufficiently problematic to cast considerable doubt on the utility of findings from empirical studies of this phenomena. Their argument hinges on the normative position that cooperation viewed from one perspective may "simply be conflict in disguise" (Eckhardt and Azar, 1978, p. 1235). This implies, for some, that conflict and cooperation can only be judged on normative grounds and leads to the position that conflict is bad and cooperation is good. Their empirical findings, however cautiously treated, do suggest that in North American and European international relations cooperation is considerably more extensive than is conflict (which dominates the international relations of the Third World). (Azar and Havener (1976) have also shown that cooperation is considerably more difficult for expert judges to scale consistently.)

The research reported here develops models of the dynamic relationships of cooperation and conflict and examines them with respect to foreign-policy interactions of the Soviet Union, the United States, Israel, Japan, France, and Egypt since World War II.

2 THEORETICAL SPECULATION

So pervasive is the usage of action–reaction conceptualizations in international politics that little justification seems to be necessary to posit that diplomatic behavior, comprising conflict and cooperation alike, is in part governed by or at least partially described by this mechanism. Simply put, the argument rests on the assumption that foreign-policy behavior sent from one nation to another is a direct consequence of the directed behavior of that nation toward the initiator. Likewise, specific types of behavior – most notably conflict and cooperation – are also often posited to be reciprocal. Under this model foreign-policy behavior between specific nations is conceptualized as a tit-for-tat phenomenon: conflict sent engenders conflict received. Similarly cooperation exhibits the same positive feedback characteristic.

Such a simple model of foreign-policy behavior has several distinct shortcomings. In the first place it seems highly unlikely that a phenomenon as complex as and involving as many issues and actors as international politics can be accurately described, let alone be predicted, by such a simplistic model. Foreign policy is, after all, policy – however disjointed it may appear. It involves planning in all its dimensions including goal setting, strategy, tactics, logistics, and evaluation, as well as reaction to external stimuli. Moreover, if indeed foreign-policy behavior has its own dynamic, however simple, it is clear that some constraints are in place in that dynamic. Conflict does often escalate but rarely does it escalate unabated. Nor does cooperation in the international system appear to be so impervious to other influences as to permit speculation about unbounded cooperation spirals. Foreign policy is marked almost everywhere by shifts and fluctuations, not only in goals but also in resources and commitment to carry through those delineated objectives. Domestic political events (such as elections, revolutions, and party realignments) and less discrete domestic forces throughout the world (such as public-opinion vacillations) would appear on the surface to have a considerable impact on the conduct of foreign policy.

Despite these considerable shortcomings the action–reaction dynamic remains a viable building block in attempts to model foreign-policy behavior. The basic stimulus–response model may be described by the well-known Richardson arms-race equations.

Instead of working with the continuous formulations developed by Richardson for describing arms races (1919–1960), we give a discrete formulation for the conflict between two hypothetical nations using the equations

$$X_t = a_1 X_t - 1 + a_2 Y_t \tag{1}$$

$$Y_t = b_1 Y_t - 1 + b_2 X_t \tag{2}$$

Similarly cooperation between these two nations may be given by

$$W_t = c_1 W_t - 1 + c_2 Z_t \tag{3}$$

$$Z_t = d_1 Z_t - 1 + d_2 W_t \tag{4}$$

For two hypothetical nations (1 and 2), X_t represents the conflict behavior of nation 1 toward nation 2 at time t while Y_t is the conflict behavior of nation 2 toward nation 1 during the same period; W_t and Z_t are the respective cooperation behaviors of nations 1 and 2 toward one another at time t. This specification of the action–reaction dynamic goes beyond the tit-for-tat positive feedback mechanism of the stimulus–response model by including damping terms ($a_1 X_t - 1$, $b_1 Y_t - 1$ and $c_1 W_t - 1$, $d_1 Z_t - 1$) which may constrain the growth (or decline) of the behavior modeled.

In these highly simplified single-equation models of foreign-policy behavior the lagged endogenous variable in each equation may carry any number of theoretical interpretations but essentially represents the influence of past behavior on the execution of present behavior. This past-on-present influence, in these equations, may be characterized as a nonadaptive process; i.e. the present carries a memory trace from the past but only for the short term (lags of one period). More importantly, memory does not serve as the basis for modifying the causal mechanism that is perceived to be generating foreign policy. For example, the large failure of an invasion like the Bay of Pigs would not, in this model, serve to retard similar future behavior. Both successes and failures in past policies are treated identically in such a model: they are emulated (to a greater or lesser extent) in present and future foreign policies.

Other conceptualizations are also possible. It may simply be that the spiral of exogenous action–reaction is damped via "fatigue" (Richardson (1960), p. 15). Econometric interpretations rest on the declining lag scheme of Koyck (1954), the adaptive-expectations model of Cagan (1956), and the partial stock adjustment conceptualization of Nerlove (1958). These various conceptual interpretations of identical equations suggest that in contradistinction to the foregoing interpretation there is an adaptive mechanism embedded in the causal mechanism generating the behavior in question which has long-term consequences.

Considerable empirical evidence exists for such speculations about the action–reaction dynamic in international politics (see, for example, Phillips (1977)). In some recent studies Wilkenfeld et al. (1979a) and Hopple (1978) have examined foreign-policy behavior partitioned into three categories (cooperative actions, verbal conflict, and force actions) by examining as explanatory schema societal, interstate, and global components. This framework has been juxtaposed with the behavior-begets-behavior explanations suggested earlier. Their findings are particularly illuminating in suggesting that in general the inclusion of action–reaction dynamics dramatically increases the explanatory power of models used to predict different types of behavior. (WEIS event-interaction data were used to measure these three categories of foreign-policy behavior in 56 polities yearly throughout the period 1966–1970.) Especially interesting is the finding that as the intensity of and risks involved in interaction increase (i.e. moving from cooperation to verbal conflict and then to force actions) the explanatory salience of the action–reaction dynamic also increases.

If the characterization presented in eqns. (1)–(4) may be called the behavior-begets-behavior model incorporating memory, the following specification may be termed the mix-begets-mix model. Drawing on the arguments posed earlier, it appears equally reasonable to presume that both conflict and cooperation responses are each likely to be conditioned not solely in response to similar stimuli (for example, conflict for conflict) but rather in response to the behavioral mix of conflict and cooperation, i.e. in response to the range of behaviors received. Additionally, memory – whether conceptualized in terms of bureaucratic momentum, adaptive mechanisms, or system memory – of this mix of conflict and cooperation behavior received may also be important in explaining the ways in which nations respond to each other's actions. A merged model which captures these additional elements is presented by the following general equations for the hypothetical nations 1 and 2 (the definitions of the variables are given earlier):

$$X_t = a_1 X_t - 1 + a_2 Y_t + a_3 W_t - 1 + a_4 Z_t \tag{5}$$

$$Y_t = b_1 Y_t - 1 + b_2 X_t + b_3 Z_t - 1 + b_4 W_t \tag{6}$$

$$W_t = c_1 W_t - 1 + c_2 Z_t + c_3 X_t - 1 + c_4 Y_t \tag{7}$$

$$Z_t = d_1 Z_t - 1 + d_2 W_t + d_3 Y_t - 1 + d_4 X_t \tag{8}$$

This specification embeds the action–reaction and memory dynamic within the fabric of the mix of conflict (the Xs and Ys) and cooperation (the Ws and Zs). Equations (5)–(8) suggest that for two given nations (say the United States and the Soviet Union) with corresponding respective conflict and cooperation behaviors represented by W, X, Y, and Z, behavior sent, irrespective of type, is a function of past levels of conflict and cooperation sent and of recent levels of conflict and cooperation received.

Essentially, in the foregoing two models are presented which share the action–reaction and momentum mechanisms. These two models are both structured only in terms of foreign-policy behaviors. As such they have recognized shortcomings. Notable among these is the fact that they consider dyadic behavior only; no third-party interactions, typically associated with much superpower interaction, are present. National attributes which are often associated with certain types of behavior (e.g. level of development, economic and military power, and position in the international hierarchy) are excluded as explanatory factors. Also, these models do not include any internal domestic variables which might impinge on or stimulate foreign-policy decision making (although it is possible to give domestic interpretations to each of the factors involved in the equations). To the extent that these types of explanations are both widely proffered and excluded in the foregoing formulations, the particular specification given may provide a difficult test for the theoretical notions which are included. In the following sections, such a test is described.

3 METHOD

3.1 Case Selections

In order to subject the foregoing ideas to a rigorous empirical test, several pairs of nations were chosen for analysis. The reciprocal conflict and cooperation behaviors of the United States and the Soviet Union were selected because of the importance of these two superpowers to the contemporary international system. Moreover, the United States and the Soviet Union have postured and have been perceived as global adversaries in the era since World War II, each leading a bloc of "faithful" allies in their superpower rivalry. The second group of nation pairs selected consists of the United States and three of its contemporary allies: France, Israel, and Japan. Each of these countries holds a different, though special position in US alliance relations. France has been allied with the United States since the end of World War II and has been strongly aligned with the western alliance; however, since the late 1950s France has been critical of much US policy in the international arena and has of course withdrawn from the military aspects of the Atlantic alliance. Israel represents a "strong" US ally in the sense that it is dependent on US support in a number of areas, not the least of which is military and economic aid. Furthermore, it is an ally which has been involved in a hot and cold running regional conflict for the last 30 years. The various regional and international cross-pressures brought on the United States by the conflict have been considerable. Japan, in contrast, is considered to have had until very recently a very harmonious economic and political alliance based almost solely on cooperation with US interests. One other nation pair was added to the sample selected for analysis: Israel and Egypt. This case was chosen because it represents a nation pair with high conflict potential at the regional – not global – level. In a way these two nations may be seen as regional adversaries and rivals in the same sense that the United States and the Soviet Union are perceived by many as global rivals.

3.2 Data Selection and Indicator Choice

Event-interaction data aggregated to yearly intervals were chosen as the primary data for analysis in the ten cases analyzed. Two exemplary sources of such data exist. The WEIS uses a 64-category coding scheme which is applied to newspaper articles which appear in the New York Times (Daily). This data set is available from 1966 to the present and had been widely used by researchers in international politics. It currently provides the data base for one real-time early-warning and monitoring system employed by the US government. (See Andriole (1979) or Daly and Davies (1978) for a description of this system. Daly and Andriole (1979) provide an example of its application to forecasting in the Middle East.) Against the robust advantages of this data set, which combines a strong tradition of research and policy usage with the availability of up-to-date data, there is one major disadvantage. WEIS data only exist back to 1966. Thus they do not cover the 1950s and early 1960s in which much of the dynamic of the so-called "cold war" emerged and evolved.

A second source of event-interaction data which is both extensive and longitudinal is COPDAB, which was developed by Azar and Sloan (1975). This source is not as extensive as the WEIS data set in that it includes a much smaller universe of nation pairs: it focuses on the interactions of 31 nations. Each event interaction has been scaled on a 15-point scale by trained expert coders. On this scale one point is given to the most cooperative event between two nations and a scale value of 15 is given to the most conflictual event. Psychometric scaling techniques are then employed to determine the scale weights. (See Azar and Sloan (1975, pp. vii–x), Azar (1980), and Sloan (1973) for discussions of the procedures involved.) A dimensions of interaction (DI) score is then obtained by multiplying scale points by scale weights. (No corresponding psychometric scaling is present in the WEIS data, though one could be applied to them.) One major advantage of the COPDAB data set is that it extends back in time to 1948, capturing the early years after World War II. Its major disadvantage may lie in the fact that it extends forward only to 1973, thus excluding the most recent years. According to many accounts it is during these years that a new dynamic template was/is being forged for international politics. COPDAB also uses many regional news sources – especially for the Middle East – as well as the New York Times.

Some examination of the comparability of these two data sets has been reported (Howell, 1979). Basically there is some indication that for selected years, the two data sets are highly comparable for US–Soviet interactions:

> "General conclusions are that for both data sets there is no significant distinction between the raw frequency and the weighted value measures of the US–USSR interaction and that frequency and weight can be used interchangeably, that US–USSR and USSR–US cooperation values . . . intercorrelate highly . . . and that the two sets can be used interchangeably . . . that neither US–USSR conflict nor USSR–US conflict is highly correlated across the data sets." (Howell 1979, abstract)

Each of these two data sets therefore has both strong assets and strong liabilities. Were the time domains not so markedly different the optimal strategy would be to employ both of them. The strategy followed herein has been to use COPDAB data largely because COPDAB includes data from the first 15 years following the conclusion of World War II. It is these data which were used to estimate empirically the models presented in eqns. (1)–(4) and (5)–(8).

One strong advantage that this strategy holds is that the WEIS data set remains "uncontaminated" by the testing procedure, and thus can be used both as a "postdictive" (using the data for 1966–1973) check on the estimates derived from using the COPDAB data set and as a source of ex post ante observations against which the extrapolations of the estimated models can be rigorously examined.

3.3 Model Evaluations

Four explicit guidelines were followed in the empirical evaluations which are described below. The postulated relationships represented in eqns. (1)–(8) were each examined using classical regression techniques. Estimation, respecification, and reestimation were variously employed in order (a) to maximize the statistical significance of estimated regression coefficients, (b) to eliminate statistically nonsignificant coefficients via elimination of variables, (c) to minimize, where present, any statistically significant autocorrelation, and (d) to maximize the variance explained. These four constraints were utilized to select the estimates which best satisfy the constraints in each case examined.

Operationally, this exploratory test was conducted as follows. Ordinary least-squares (OLS) estimates of each of eqns. (1)–(8) were obtained. (Here, and through all the subsequent analysis, the time-series processor was used to obtain estimates. Independent calculations were used to compute certain statistical information (e.g., Durbin's h).) Subsequently, autoregression disturbances of the first order were examined through reestimation of each equation utilizing the iterative Cochrane–Orcutt algorithm, a Generalized Least-Squares (GLS) technique. Statistically significant autocorrelation was tested at the 0.05 probability level (t test on estimated value of the autocorrelation coefficient ρ). If autocorrelation was detected the GLS estimates were retained; otherwise, the OLS estimates were used. t tests (at the 0.05 probability level) were also utilized to test for the statistical significance of the estimated coefficients for each of the independent variables. Variables with nonsignificant coefficients were deleted from the particular equation in question and the estimation procedure was repeated for that equation.

For eqns. (4)–(8) (the merged conflict and cooperation model) the same strategy was followed for each nation pair. However, one additional criterion was employed. The mix-begets-mix formulation was retained over the behavior-begets-behavior formulation only if on satisfying all other constraints it resulted in an increase in the variance explained (measured by the adjusted coefficient of determination) *and* also resulted in statistically significant regression coefficients (again at the 0.05 probability level) for at least one conflict and one cooperation variable. Thus the more complex formulation involving both conflict and cooperation as explanatory factors was retained only if it was both statistically and conceptually more robust. This criterion was intended to enforce the notion of parsimony, i.e. that the model which is the least complex is, all other things being equal, preferable.

Before proceeding to the reporting and analysis of results we should point out that the procedures employed and described herein tend to be very conservative in terms of type-II error. Variables are deleted from the analysis unless they yield highly significant statistical results. Also, by definition there will be a set of estimates which best meets these criteria. "Best" should not be equated with nor imply "good" or "satisfactory". The consequences of this strategy in a brush-clearing investigation such as this are severe. All the brush, and perhaps some of the small trees, are eliminated. (It can of course be argued convincingly that in a preliminary test such as this one should seek to employ methods which are highly inclusive in retaining all the plausible explanatory factors.)

4 DESCRIPTION AND ANALYSIS

Table 1 presents the estimates and statistics resultant from employing the strategy outlined below to eqns. (1)–(4) for each case selected. Only the results which satisfy the constraints outlined in Section 3.3 are presented (complete results may be obtained from the author).

TABLE 1 Estimates of reciprocal conflict and cooperation equations, via OLS or via GLS with correction for autocorrelation with the Cochrane–Orcutt iterative technique using yearly COPDAB data (1948–1972).

Coefficients[a]	Conflict	Cooperation	Conflict	Cooperation
Nation pair: United States–Soviet Union				
	United States		Soviet Union	
Domestic reaction	0.94[b]	–[c]	0.36[b]	–[c]
Foreign reaction	–[c]	0.78[b]	0.88[b]	1.19[b]
Autocorrelation	– 0.65[b]	0.38 (t = 1.9)	–[c]	–[c]
Durbin (Watson)	h = – 0.26	d = 2.08	h = – 1.62	d = 1.31 (inconclusive)
Variance explained	0.15	0.19	0.23	0.81
RMSE	339.3	95.1	465.5	121.9
Method	GLS	GLS	OLS	OLS
Nation pair: United States–France				
	United States		France	
Domestic reaction	0.47[b]	–[c]	0.54[b]	0.20[b]
Foreign reaction	0.38[b]	1.38[b]	0.56[b]	0.56[b]
Autocorrelation	– 0.67[b]	–[c]	– 0.45[b]	–[c]
Durbin (Watson)	h = 0.12	d = 1.51	h = 1.66[b]	h = 0.73
Variance explained	0.42	0.73	0.00	0.73
RMSE	71.7	97.4	77.6	58.4
Method	GLS	OLS	GLS	OLS
Nation pair: United States–Japan				
	United States		Japan	
Domestic reaction	–[c]	–[c]	0.55[b]	–[c]
Foreign reaction	0.51[b]	0.83[b]	0.76[b]	0.75[b]
Autocorrelation	–[c]	0.70[b]	–[c]	0.86[b]
Durbin (Watson)	d = 1.91	d = 2.00	d = 2.22	d = 2.13
Variance explained	0.51	0.41	0.33	0.57
RMSE	37.1	76.7	50.4	71.3
Method	GLS	GLS	OLS	GLS
Nation pair: United States–Israel				
	United States		Israel	
Domestic reaction	0.36[b]	0.27[b]	–[c]	–[c]
Foreign reaction	0.66[b]	1.10[b]	0.86[b]	0.63[b]
Autocorrelation	– 0.47[b]	–[c]	–[c]	–[c]
Durbin (Watson)	h = 0.76	h = 0.10	d = 2.22	d = 1.46
Variance explained	0.58	0.41	0.49	0.49
RMSE	57.7	112.5	58.6	83.6
Method	GLS	OLS	OLS	OLS

TABLE 1 (*Continued*)

Coefficients[a]	Conflict	Cooperation	Conflict	Cooperation
Nation pair: Israel–Egypt				
	Israel		Egypt	
Domestic reaction	–[c]	–[c]	–[c]	–[c]
Foreign reaction	1.80[b]	1.73[b]	0.52[b]	0.54[b]
Autocorrelation	–[c]	–[c]	–[c]	–[c]
Durbin (Watson)	$d = 2.34$	$d = 1.95$	$d = 2.30$	$d = 1.97$
Variance explained	0.90	0.90	0.89	0.89
RMSE	1000.3	25.9	525.2	14.2
Method	OLS	OLS	OLS	OLS

[a] Domestic-reaction and foreign-reaction coefficients are unstandardized regression coefficients. Autocorrelation coefficients are ρ values estimated through the Cochrane–Orcutt iterative technique, convergent to the third decimal place. Durbin (Watson) values are Durbin's h for equations with lagged endogenous variables and the Durbin–Watson d statistic for all others. Variance explained is the coefficient of determination corrected for degrees of freedom and number of variables; RMSE is the root mean squared error.
[b] Significant t statistic at 0.05 probability level.
[c] Nonsignificant t statistic at 0.05 probability level.

4.1 Case Analysis: US ⟷ Soviet Behavior

Turning to the results of the iterative estimation procedure outlined earlier for eqns. (1)–(4) (the behavior-begets-behavior model) one is struck by the different dynamics which seem evident in US versus Soviet foreign-policy behaviors. In descriptive terms, the US conflict behavior to the Soviet Union is *not* significantly influenced by receipt of Soviet conflict behavior but is governed by its own internal dynamic. Both in terms of the negative autocorrelation present and in terms of the size of the domestic-reaction coefficient US → Soviet conflict appears to be largely a trend-dominated memory-laden phenomenon which is largely uninfluenced by Soviet behavior as measured and modeled here. However, the amount of variance explained in this equation is a slight 15%. Thus it would be a mistake to accept this interpretation categorically without further testing since 85% of the variance remains to be explained by some combination of factors as yet unknown.

Soviet → US conflict behavior is found to be positively reactive both to past Soviet behaviors and to conflict received from the United States. As in the US → Soviet case, the amount of total variance explained is small (23%). These two estimated equations when coupled would suggest that the US ⟷ Soviet conflict interactions are determined not so much reciprocally as by US actions, their trend or momentum, and by the reaction of the Soviet Union to those actions. Very plausibly this could be an artifact resulting from the use of data ethnocentrically encoded by Americans using primarily news sources. However, the conflict behaviors are largely determined by other influences which are outside the specific domain of these equations.

Unlike the conflict behaviors, the cooperative US ⟷ Soviet behaviors do not exhibit asymmetry in the dynamic causal structure as represented by the models estimated here. Neither the Soviet Union nor the United States show strong domestic-reaction coefficients, indicating the absence of "cooperative momentum or inertia" (memory). However, each appears to react in a strong positive fashion to cooperative behavior received. For the US → Soviet case, again the variance explained is not large (19%) and although the test for autocorrelation is not significant it is close to being so. For the Soviet → US case, over 80% of the total variance is explained. Here the autocorrelation test does not allow one to accept the presence of autocorrelated error components but the Durbin–Watson statistic falls within the inconclusive region. The United States also reacts and responds less strongly to conflict than does the Soviet Union ($0.94 < 0.36 + 0.88$). The Soviet Union reacts much more strongly to received cooperation than does the United States ($1.19 > 0.78$).

Perhaps what is most surprising in these results is that they appear to stand much of the conventional wisdom about US ⟷ Soviet foreign-policy behaviors on its head. Especially for the period 1950–1970, one would expect on the basis of that wisdom that the cold-war posturing of both countries was such that conflict would be highly present and well explained by an action–reaction causal mechanism. Others (e.g. Holsti et al., 1968) have found this type of model to be more applicable in high-risk crisis-driven situations. Accordingly, in the high-tension and somewhat crisis-prone 1950–1970 era one would expect a high degree of similarity to the action–reaction model. In contradiction the results suggest that the action–reaction notions do not readily apply to US ⟷ Soviet foreign-policy conflict behaviors. Instead they seem to be more applicable to US ⟷ Soviet cooperative foreign-policy behavior.

Several plausible explanations for these findings might be offered. It could simply be that the conventional wisdom is incorrect – it often is. Second, the simplification offered and its operationalization herein may be too grossly constructed to capture the nuance of the action–reaction dynamic (for example, using yearly time aggregations to represent decision-making outputs which are generated daily). Third, too many other relevant influences have been omitted for the models to prove very robust. Likely candidates include the mix-begets-mix model and domestic political influences such as presidential election campaigns in the United States.

In addition it may be that the action–reaction model explains a large part of US ⟷ Soviet behavior but this is not visible in the data and model which reflect only dyadic interactions. This explanation seems to be highly plausible for a number of reasons. First of all, despite the variation in "temperatures", the nomenclature "cold war" did evolve in large part as a recognition of the salience of nuclear military power. The US ⟷ Soviet rivalry was argued by many to be self-inhibited in the sense that decision makers in each nation "understood" and often shied from confrontations which appeared to be escalatory. Could it be therefore, despite the well-known approaches to the brink, that Richardson presaged the lack of fit between the action–reaction process and US ⟷ Soviet conflict behaviour when he noted that "the equations are merely a description of what people would do if they did not stop to think" (Richardson, 1960, p. 12). Thus it could be that the inherent dangers in escalation of nuclear superpower conflict spirals worked against their occurrence. It also seems to be likely that although direct confrontation between the United States and the Soviet Union tended not to occur much US ⟷ Soviet conflict has been in the past (and continues to be) sublimated in somewhat veiled antagonisms directed toward one another through third parties.

4.2 Case Analysis: US ⟷ Allies Behavior

The three chosen nation pairs analyzed in this section show quite different patterns of both action and reaction in their foreign-policy behaviors. However, some interesting patterns do emerge.

In general it may be said that a high degree of variance in both the conflict and the cooperation patterns of these three nation pairs is explained by the model posited. Although in one case (French → US conflict behavior) the variance explained once the autoregressive trend is removed is virtually nil, the mean of the adjusted coefficient of determination for all 12 regressions is almost 50% (0.47). This stands in contrast to the low levels of covariation in US ⟷ Soviet behaviors.

More importantly it would appear that if these three nation pairs reflect an adequate and representative picture of the general tenor of US foreign-policy behavior with respect to its allies then the action–reaction dynamic would appear to be much more solidly in place than is the case for US ⟷ Soviet behaviors. The foreign-reaction coefficients are statistically significant in each instance examined. Furthermore, these coefficients are all positive and tend to be quite strong, ranging from a low of 0.38 to a high of 1.38. From this one would conclude that the reactivity to behavior received is quite high in these cases chosen to represent a wide range of behaviors between the United States and its allies. The domestic-reaction coefficients demonstrate considerably more variability. Only six of the 12 examined are statistically significant. Of these the domestic-reaction coefficient is stronger than the foreign-reaction coefficient in only one case. This suggests that the action–reaction dynamic for US ⟷ Allies behavior is largely determined by a behavior-sent behavior-received model with moderate amounts of memory included.

Additionally, one notes from these findings that the United States tends to react less strongly to conflict received from the allies than the allies tend to react to conflict directed to them by the United States. With respect to cooperation, exactly the opposite is the case. US allies tend to respond with less magnitude to cooperation received than does the United States. It can also be observed that in general the United States tends to "value" cooperation over conflict by a ratio of about 2:1. In their relations with the United States the three allies (France, Japan, and Israel) each have conflict and cooperation coefficients for which no marked differences are observable. These patterns contrast sharply with the US ⟷ Soviet case.

4.3 Case Analysis: Israel ⟷ Egypt

The last case chosen for analysis consists of the conflict and cooperation sent to and received from one another by Israel and Egypt. This case represents an escalatory spiral of both conflict and cooperation in which neither autocorrelation nor domestic reaction appears to play a significant role. Simply, behavior received yields behavior sent. Virtually all the covariation in this case is explained (roughly 90%) by foreign reactivity. The data also suggest that the Israeli foreign-policy behavior is over three times more reactive to Egyptian behavior than Egyptian behavior is to Israeli behavior. Moreover, Egyptian coefficients for given constant inputs over time would tend to deescalate since the coefficients suggest an Egyptian foreign-policy output to Israel of about 0.5 times the input from Israel. The Israeli coefficients are highly escalatory since for every unit of Egyptian behaviour received a response of about 1.7 times the input may be expected. It is important to recognize that this is the case for both the conflict and the cooperation equations. It would seem to follow therefore that the tenor of Israeli ⟷ Egyptian relations is firmly embedded in an escalatory action–reaction process. Within that process, changes in the behavior of Egypt toward Israel will engender greater changes in the Israeli behavior than will changes in Israeli behavior toward Egypt.

4.4 The Mix-Begets-Mix Model

The model suggested in eqns. (5)–(8) is founded on the idea that conflict and cooperation are each intermixed in the foreign-policy behaviors of nation pairs and that each behavior is reactive to both conflict and cooperation sent and received. Table 2 presents the results of the empirical examination of this notion.

TABLE 2 Estimates of merged reciprocal conflict and cooperation equations via OLS or via GLS with correction for autocorrelation with the Cochrane–Orcutt iterative technique using yearly COPDAB data (1948–1972).

Coefficients[a]	Soviet Union cooperation with United States	Japan cooperation with United States	Israel conflict toward United States	United States conflict toward Israel
Same behavior				
Domestic reaction	–[c]	–[c]	–[c]	0.47[b]
Foreign reaction	1.02[b]	0.60[b]	0.63[b]	0.55[b]
Different behavior				
Domestic reaction	0.13[b]	–[c]	0.18[b]	–0.14[b]
Foreign reaction	–[c]	0.79[b]	–[c]	0.19[b]
Autocorrelation	–[c]	0.87[b]	–[c]	–0.45[b]
Durbin (Watson)	$d = 1.83$	$d = 1.84$	$d = 1.98$	$h = 0.89$
Variance explained	0.86	0.72	0.53	0.65
RMSE	101.5	55.9	59.1	46.6
Method	OLS	GLS	OLS	GLS

[a] Same behavior refers to the conflict–conflict and cooperation–cooperation pairing. The other coefficients are defined in footnote *a* to Table 1.
[b, c] See corresponding footnotes to Table 1.

For the 20 instances which were examined the mix-begets-mix model was able to provide substantial theoretical and empirical improvement in only four cases. In only one nation pair (US → Israeli conflict) do the results suggest that the mix-begets-mix model is statistically significant in all the parameters examined. In that case the mechanism generating US behaviors appears to be weakly influenced by the receipt of Israeli cooperation directed to the United States. However, the same trait reactivity (conflict to conflict) is much stronger (by a factor of roughly 2).

In general these results tend to reemphasize the domination of foreign reaction over domestic reaction in the foreign-policy behaviors of nation pairs. The results also suggest quite strongly that conflict and cooperation may be intermixed quite substantially in the behaviors of nations but that they appear to be most accurately described by separate models which focus on the receipt and memory of similar behavior from their prospective targets.

5 RETEST AND EXTENSION

5.1 Retest

It is useful to conduct a reexamination of the foregoing tests with an independent data set. Such a retest should provide important information about the generalizability of the results gleaned earlier as well as suggest their sensitivity to changes in the data. The WEIS data provide a viable source of such (largely) independent data. (They are largely independent because the New York Times serves as a source in both the COPDAB and the WEIS coding procedures.) These data are available from January 1, 1966 to December 31, 1977, for all major national actors in the international system and specifically for the nation pairs utilized in the empirical analysis described earlier. As such the data permit the independent retest of the notions about conflict and cooperation patterns explored already.

The design to be followed involves two major ingredients: (1) reestimation of eqns. (1)–(8) for each nation pair, utilizing the iterative least-squares strategy employed previously, and comparison of the two sets of parameter estimates; (2) ex post facto forecasts of WEIS data based on the reestimated parameters obtained in step (1).

Before we proceed to these facets of analysis it is necessary to elaborate on the design. The availability of WEIS data in unaggregated format allows the examination of the hypothesized conflict and cooperation mechanisms in time slices which are considerably shorter than the yearly aggregations available from COPDAB data. This permits one to focus more closely on the dynamics of changing patterns of conflict and cooperation. This consideration is quite important from a theoretical point of view inasmuch as foreign-policy behavior occurs frequently if not continuously throughout the year and may change markedly throughout any arbitrary 12-month period. Yearly aggregations presume homogeneous behavior for the entire 12-month period.

Second, the time frames for the COPDAB and WEIS data, however aggregated, are quite distinct. Yearly COPDAB data are available from 1948 to 1973. Thus there is considerable overlap of the WEIS with COPDAB. Accordingly the WEIS samples have been divided into two subsamples. The first is the direct-comparison sample, consisting of data in the overlap period (1966–1972). The second set of observations (1973–1977) comprise the ex post facto forecast subsample.

Additionally, the WEIS coding scheme for characterizing event-interaction data has roughly four times as many categories (64) as are available with COPDAB. In many previous studies actions ranging from "yield" to "propose" have been classified as cooperative, while those ranging from "reject" to "force" have been treated as conflict interactions.

Such twofold classification seems quite reasonable on a priori grounds; however, recent work has shed additional light on this matter.

Wilkenfeld et al. (1979b) have factor analyzed WEIS data by nation and by year for the 56 nations that were most active in the international system from 1966 to 1970. Their results suggest that the a priori classification that is typically employed is well approximated by the data. However, three (not two) factors emerged. The first two correspond to cooperation (49% variance) and conflict (24% variance). Moreover, actions ranging from "yield" to "propose" tend to load highly on the cooperation factor and low on the conflict factor. Conversely, the conflict factor is loaded highly on by events characterized by the codes ranging from "reject" to "seize" while for the most part these categories do not load highly on the cooperation factor. One notable exception is embodied in the emergence of a third statistical factor, independent of the previous two, on which only events characterized by the use of force load highly. This suggests that this threefold classification would not mix together what on the surface appear to be separate dimensions of foreign-policy behavior: conflict and force. The retest seeks to be informed by this new finding in the literature. However, rather than employing the factor scores developed for the large sample examined in the study of Wilkenfeld et al. (1979b), we use a simple additive aggregation. Cooperative events are those which are characterized by event codes ranging from "yield" to "propose", conflictual events those with codes from "reject" to "seize", and force events those characterized by (a) noninjury destructive acts, (b) nonmilitary injury or destruction, and (c) military engagements.

In the remainder of this section we examine the eight basic equations explored earlier. Essentially the retest involves substitution of quarterly WEIS data on constructive diplomatic and nonmilitary conflict behavior for each of the nation pairs for the previously explored COPDAB data set. The iterative search procedure given earlier for delineating the best-fitting model is then followed. Finally, the results are analyzed and compared to those obtained earlier.

Typically, retests of this sort are designed to examine the equality of coefficients from different samples. The Chow test, the most widely used technique, is constructed by pooling together both subsamples into one time series (Chow, 1960). Estimates for the pooled time series are compared with estimates from each subsample by constructing an F test on the ratio of explained to unexplained variance (examining the null hypothesis that each individual regression coefficient in each sample is *not* statistically different from the others).

The presence of temporal overlap between the WEIS and COPDAB data sets, interdependence of the basic source materials, difference in coding categorizations, and the different temporal aggregations employed in each of the two basic sets of time series suggest the difficulty of applying the Chow test in this study. Moreover, the Chow test is a relatively easy test to pass insofar as it infers information about the equality of each individual regression coefficient from the F statistic in each subsample.

Accordingly the entire testing procedure utilized in analyzing the COPDAB data set was repeated with the WEIS data, permitting the examination of the retest in considerable detail. Table 3 presents the results from the reanalysis of eqns. (1)–(4) utilizing the quarterly WEIS data from 1973 to 1977. It is directly comparable to Table 1 except insofar as the units from the COPDAB data set (scaled dimensions of interaction) are not directly translatable into WEIS units of interaction (categorized event aggregations). This

TABLE 3 Estimates of reciprocal conflict and cooperation equations via OLS or via GLS with correction for autocorrelation with the Cochrane–Orcutt iterative technique using quarterly WEIS data (1966–1972) for replication of results presented in Table 1.

Coefficients[a]	Conflict	Cooperation	Conflict	Cooperation
Nation pair: United States–Soviet Union				
	United States		Soviet Union	
Domestic reaction	–[c]	–[c]	–[c]	–[c]
Foreign reaction	0.47[b]	1.16[b]	1.66[b]	0.82[b]
Autocorrelation	–[c]	–[c]	–[c]	–[c]
Durbin (Watson)	$d = 2.18$	$d = 1.82$	$d = 2.11$	$d = 1.74$
Variance explained	0.48	0.85	0.35	0.86
RMSE	5.7	10.0	4.7	4.0
Method	OLS	OLS	OLS	OLS
Nation pair: United States–France				
	United States		France	
Domestic reaction	–[c]	0.19[b]	0.38[b]	–[c]
Foreign reaction	0.61[b]	0.67[b]	0.71[b]	1.09[b]
Autocorrelation	–[c]	–[c]	–0.54[b]	–[c]
Durbin (Watson)	$d = 2.22$	$h = -0.53$	$h = 0.38$	$d = 1.91$
Variance explained	0.45	0.65	0.23	0.64
RMSE	1.0	2.0	1.1	2.7
Method	OLS	OLS	GLS	OLS
Nation pair: United States–Japan				
	United States		Japan	
Domestic reaction	–[c]	–[c]	–[c]	0.25[b]
Foreign reaction	0.53[b]	0.65[b]	1.17[b]	0.78[b]
Autocorrelation	–[c]	–[c]	0.37[b]	–[c]
Durbin (Watson)	$d = 1.11$[b]	$d = 2.15$	$d = 1.91$	$h = 1.39$
Variance explained	0.41	0.27	0.49	0.27
RMSE	1.3	4.7	1.7	5.2
Method	OLS	OLS	GLS	GLS
Nation pair: United States–Israel				
	United States		Israel	
Domestic reaction	–[c]	0.24[b]	0.55[b]	–[c]
Foreign reaction	0.73[b]	0.87[b]	0.46[b]	0.83[b]
Autocorrelation	–[c]	–0.46[b]	–0.68[b]	–[c]
Durbin (Watson)	$d = 2.32$	$h = -0.79$	$h = -0.68$	$d = 2.28$
Variance explained	0.28	0.75	0.42	0.76
RMSE	1.3	2.4	1.2	2.3
Method	OLS	GLS	GLS	OLS
Nation pair: Israel–Egypt				
	Israel		Egypt	
Domestic reaction	–[c]	0.48[b]	0.23[b]	–[c]
Foreign reaction	0.72[b]	0.59[b]	1.00[b]	0.38[b]
Autocorrelation	–[c]	–0.36[b]	–[c]	0.19[b]
Durbin (Watson)	$d = 2.4$	$h = -1.44$	$h = -0.96$	$d = 2.16$
Variance explained	0.70	–0.00	0.70	0.00
RMSE	3.7	2.2	4.1	1.5
Method	OLS	GLS	OLS	GLS

[a, b, c] See corresponding footnotes to Table 1.

fact accounts for the rather large difference one observes between the root mean squared error (RMSE) when comparing values between Table 1 and Table 3.

The most striking finding which is similar across the tests involving each of these data sets is that the foreign-reaction coefficient is strong, statistically significant, and positive in every instance save one. The only exception to this rule is in the COPDAB sample (Table 1) for US conflict behavior directed toward the Soviet Union. The foreign reactivity, as represented by these results, ranges from a response of 0.38 units of conflict or cooperation behavior for each unit received to a high of reactive responses of nearly double (1.8).

In spite of the strength of this finding it must also be pointed out that there are a large number of differences between the results in Tables 1 and 3. The pattern of significant estimated coefficients is different as often as it is the same in each of the two tests conducted. This means that the significance of the domestic reaction (or memory) is unstable from the yearly COPDAB to the quarterly WEIS score. This domestic-reaction coefficient, where significant, is always positive in each of the two tests; however, it is only significant in each set in seven of the potential cases. In fact domestic-reaction coefficients are found to be strong in seven of the WEIS nation pairs while they are strong in eight of the nation pairs examined with COPDAB data. A large difference might have suggested that domestic reaction was related to the temporal aggregation used, i.e. that memory of what has transpired in the past is either short term or long term but not both. Such an inference cannot be supported by the analyses presented here, however.

The overall amount of variance explained, as represented by the corrected coefficient of determination and by the RMSE, is relatively high in each sample. In general the WEIS data are more well explained than the COPDAB data though there are numerous exceptions. (Care should be taken in making comparisons of these statistics. The RMSE is presented in units of the predicted variable and thus is affected by the general level of activity in a nation pair as well as the statistical robustness of the parameter estimates. It should also be pointed out that the derived estimates are not strictly speaking least squares since no constant has been included in the specified equations.)

Table 4 presents the results of the tests of eqns. (5)–(8) employing WEIS data. Again these results are directly comparable to those given in Table 2. There are two strongest results. First, the foreign reaction (for the same behavior) is again consistently strong and positive. The nation pairs for which eqns. (5)–(8) (the merged conflict and cooperation model) were found to be both statistically and conceptually superior to the single-behavior models are not the same in the WEIS and COPDAB data sets, save for the lone exception of Japanese cooperation with the United States. In this exception, however, the forms of the estimated equations are identical in each set. The general nonoverlap of results between the COPDAB and WEIS tests on the merged model points to its major inadequacy: it does not appear to be a major improvement on the single-behavior model presented in eqns. (1)–(4).

When the best-fitting model for each nation pair for each equation is compared across the WEIS and COPDAB tests, exactly one-half of the cases have exactly the same estimated form. Although not all the coefficients are equal they all have the same sign and most are of comparable magnitudes. Given the difficulty of passing a test which employs different temporal aggregations, data sets, time points, coding schemes, and data sources it would appear that there is considerable parsimony contained in the

TABLE 4 Estimates of merged reciprocal conflict and cooperation equations via OLS with correction for autocorrelation with the Cochrane–Orcutt iterative technique using quarterly WEIS data (1966–1972) for replication of the results presented in Table 2.

Coefficients[a]	United States cooperation with France	United States cooperation with Israel	Soviet Union cooperation with United States	Japan cooperation with United States	Soviet Union conflict toward United States
Same behavior					
Domestic reaction	–[c]	–[c]	0.18[b]	–[c]	–[c]
Foreign reaction	0.68[b]	0.88[b]	0.81[b]	0.56[b]	1.05[b]
Different behavior					
Domestic reaction	0.80[b]	–[c]	−0.12[b]	–[c]	–[c]
Foreign reaction	–[c]	0.88[b]	–[c]	1.98[b]	0.44[b]
Autocorrelation	–[c]	–[c]	–[c]	–[c]	–[c]
Durbin (Watson)	$d = 2.09$	$d = 1.76$	$h = -0.46$	$d = 2.07$	$d = 1.90$
Variance explained	0.72	0.78	0.89	0.43	0.49
RMSE	1.8	2.2	3.5	4.6	8.7

[a, b, c] See corresponding footnotes to Table 2.

formulations offered. In general most of that parsimony appears to be girded by the separate conflict-begets-conflict and cooperation-begets-cooperation dynamics.

In terms of specific nation-pair findings it appears that the US ⟷ Soviet Union pair is highly asymmetric in the sense that Soviet cooperation and conflict to the United States is strongly influenced by both cooperation and conflictual elements including domestic as well as foreign reactions. The behavior of the United States to the Soviet Union, in contrast, is fundamentally governed by the extent to which the United States receives either conflict or cooperation from the Soviet Union. In fact in the WEIS sample the conflict behavior of the United States to each of the other nations examined is based on a single factor: the amount of conflict behavior received. With the exception of Soviet cooperation with the United States the same may be said of Soviet cooperative diplomatic behavior.

A major reversal found in the WEIS results concerns the nation pair of Israel and Egypt. Table 1 supports the argument that Israel and Egypt are in a pure action–reaction without any domestic reaction. It further suggests that Israeli behavior toward Egypt is highly reactive both in terms of conflict and cooperation (coefficients are 1.8 and 1.73 respectively), i.e. that whatever Egypt does toward Israel, Israel returns approximately twofold. Egypt returns behavior to Israel in an approximate ratio of 0.5 : 1. However, the WEIS data do not show this strong reaction cycle. Coefficients are not as markedly different between the two nations, and the domestic reaction seems to play a moderately strong role in explaining Israeli cooperation and Egyptian conflict behaviors.

In general the retest of eqns. (1)–(8) with quarterly WEIS data met with strong success in underscoring the prominence of the importance of action–reaction cycles in explaining foreign-policy behaviors, suggesting the strength and parsimony of the single-behavior models over formulations which merged conflict and cooperation. It met with limited success in producing patterns of coefficients in one-half of the possible equations examined in the five nation pairs examined. Finally, it met with little or no success in exactly predicting this pattern in one-half of the possible equations although with one exception these cases each share a strong positive coefficient for the foreign-reaction term.

5.2 Ex Post Facto Forecasts

An additional test of the models and parameters developed in the foregoing is to conduct forecasts using them. Quarterly WEIS data from 1973 to 1977 were not utilized in the retest formulated in Section 5.1. As such these data and the parameter estimates remain uncontaminated by one another. The best-fitting equation in each nation pair, as presented in Tables 3 and 4, was used to predict quarterly data for 1973–1977. Derived coefficients were used to generate predicted scores which were then compared to the actual conflict and cooperation scores. Table 5 presents the results of this ex post facto predictive test of the model.

Comparison of RMSEs indicates that the model developed behaves quite similarly in the sample and ex post facto time series. For the US ⟷ Soviet nation pair, for example,

TABLE 5 Comparison of the "postdictive" power of the best-fit equations between the sample period (1966–1972) and the ex post facto period (1973–1977).

Nation pair		Sample period (1966–1972)		Ex post facto period (1973–1977)	
		RMSE	Mean of dependent variable	RMSE	Mean of dependent variable
United States → Soviet Union	conflict	4.7	18.5	4.7	9.6
United States → Soviet Union	cooperation	5.7	9.5	5.7	33.4
Soviet Union → United States	conflict	3.5	15.5	3.5	14.8
Soviet Union → United States	cooperation	8.7	19.6	8.6	24.0
United States → France	conflict	1.8	3.6	2.4	0.8
United States → France	cooperation	1.0	1.9	1.6	4.8
France → United States	conflict	2.7	4.1	2.3	2.3
France → United States	cooperation	1.1	1.5	2.6	4.8
United States → Japan	conflict	2.9	4.4	4.4	1.2
United States → Japan	cooperation	1.3	1.2	1.5	7.5
Japan → United States	conflict	3.6	6.3	4.3	1.3
Japan → United States	cooperation	1.6	1.9	1.6	7.5
United States → Israel	conflict	2.2	6.5	5.7	2.1
United States → Israel	cooperation	1.3	1.4	1.4	20.0
Israel → United States	conflict	2.3	5.3	4.0	2.3
Israel → United States	cooperation	1.2	1.5	2.2	16.9
Israel → Egypt	conflict	2.2	2.2	11.0	5.5
Israel → Egypt	cooperation	3.7	6.4	5.3	10.6
Egypt → Israel	conflict	1.6	1.4	2.1	6.7
Egypt → Israel	cooperation	4.1	8.9	4.5	7.7

the RMSE is virtually identical in each sample. The RMSE statistic may be interpreted as the average number of units of the dependent variable (conflict or cooperation) by which the prediction equation will overestimate or underestimate the actual value of the dependent variable on each point prediction that is made. Thus, for both periods US → Soviet conflict behavior will "mis-postdict" an average of 4.7 quarterly conflict units, i.e. slightly more than one conflict event per month. From this example it should be clear that the RMSE statistic should be looked at in close conjunction with the mean of the dependent variable. In this case the sample mean is 18.5 WEIS conflict units per quarter while the ex post facto mean is roughly one-half that figure (9.6). Therefore, while the average "mis-postdiction" is equal across both time series, the ratio of error to mean is much greater in the ex post facto time series. It is interesting to note that this ratio is reversed for the US ⟷ Soviet cooperation equations, indicating that the model predictions can be closer to the mean values in the postdicted series.

Except for the Israeli ⟷ Egyptian nation pair the conflict equations tend to have higher mean levels of conflict than cooperation. This tendency is reversed in the ex post facto period, indicating perhaps a shift to more cooperative behaviors in these nation pairs in the 1973–1977 period. The preponderance of cooperative interactions (on the average) over conflictual ones in the Middle East dyad is particularly interesting inasmuch as it sheds some light on one of the major hypotheses of this study. Periods of high conflict in Egyptian–Israeli interactions often are accompanied by period of high levels of cooperative interaction as well. This is especially true for periods during and surrounding several of the Middle East wars. Examination of the data indicate, for example, that in the third quarter of 1973 44 cooperative interactions were sent from Israel toward Egypt. During that same period there were 55 nonmilitary conflict interactions. Importantly, however, there were also 42 military force interactions not included in the conflict scores by virtue of adapting the classification suggested by the results of Wilkenfeld et al. (1979b). Further, there are periods in which periods of strong amity are not contemporaneous with high levels of hostility: e.g. during the negotiations of the last half of 1977 and extending through much of 1978. Conversely, the late 1960s and the very early 1970s show a marked tendency toward military force interactions, accompanied by very little in the way of cooperative or nonmilitary conflict behavior. Such complexity is not well modeled by the four equations offered to merge the conflict and cooperation phenomena.

6 SUMMARY

The findings reported here are quite consonant with many previous research efforts in international relations. They also stand in contrast to many others. They do not go far in explaining one of the basic contradictions of research in this area, namely that while the international system is perceived and characterized by almost everyone as a conflict-ridden and conflict-prone system our models of conflict behavior do not fare too well in predicting its outbreak. The basic contrast between the fit of cooperation versus conflict models and data is not strongly present in the cases analyzed herein: cooperation does not appear to be more patterned or better explained than conflict. In fact in the ex post facto period the conflict equations always have higher amounts of explained variance than the cooperation equations, except for the Israeli–Egyptian nation pair.

In summary, three basic results emerge. First, the testing and retesting of the developed model with both WEIS and COPDAB data met with limited success. The success was limited in the sense that not every equation in every coefficient for each nation pair was closely reproduced. However, there are strong findings which emerge in each of the tests employed, regardless of the data set or the time frame employed. Foremost is the preponderance of an action–reaction dynamic in explaining the nonmilitary conflict and cooperative diplomatic behavior of a subset of nation states to one another. In virtually every instance examined this dynamic was found to be a powerful determinant of foreign-policy behavior. Furthermore, the simple conflict-begets-conflict and cooperation-begets-cooperation formulations were found to be more powerful explanations than any of the models offered which posited that conflict and cooperation were highly related to one another.

ACKNOWLEDGMENTS

This research was supported by the Gordon Scott Fulcher Chair of Decision Making in International Affairs held by Professor Harold Guetzkow. Harold Guetzkow and Warren Silver made helpful substantive comments on an earlier draft. WEIS data were made available to me by the Cybernetics Technology Office of the Defense Advanced Research Projects Agency, which bears no responsibility, either expressed or implied, for their usage and interpretation herein.

REFERENCES

Alker H.R., Jr., and Bock, P.G. (1972). Propositions about international relations: contributions from the "International Encyclopedia of the Social Sciences". In J.A. Robinson (Editor), Political Science Annual: An International Review, Vol. 3, pp. 385–495.

Andriole, S.J. (1979). The quiet revolution in the scientific study of international politics and foreign policy. Mimeograph. Defense Advanced Research Projects Agency, Arlington, Virginia.

Ashley, R.K. (1979). Progress in the study of the long-term dynamics of conflict. Paper presented at the Annual Meeting of the International Studies Association, Toronto, Canada, March.

Azar, E.E. (1980). The Codebook of the Conflict and Peace Data Bank (COPDAB): A Computer-Assisted Approach to Monitoring and Analyzing International and Domestic Events. University of North Carolina, Chapel Hill, North Carolina.

Azar, E.E. and Havener, T.N. (1976). Discontinuities in the symbolic environment: a problem in scaling. International Interactions, 2(4): 231–246.

Azar, E.E. and Sloan, T.J. (1975). Dimensions of Interaction: A Source Book for the Study of the Behavior of 31 Nations from 1948 through 1973. International Studies Association, Pittsburgh, Pennsylvania.

Bobrow, D.B., Hopmann, P.T., Benjamin, R.W., and Sylvan, D.A. (1973). The impact of foreign assistance on national development and international conflict. Journal of Peace Science, 1(1): 39–60.

Bobrow, D.B., Hopmann, P.T., Benjamin, R.W., and Sylvan, D.A. (1973). The impact of foreign assist-424–434.

Cagan, P. (1956). The monetary dynamics of hyperinflations. In M. Friedman (Editor), Studies in the Quantity Theory of Money. University of Chicago Press, Chicago, Illinois, pp. 25–117.

Calhoun, H.L. (1971). The measurement and scaling of event data using the semantic differential. Paper presented at the Annual Meeting of the Western Political Science Association, Dallas, Texas, April 7–10.

Cattell, R.B. (1949). The dimensions of culture patterns by factorization of national characters. Journal of Abnormal and Social Psychology, 44: 443–469.
Chow, G.G. (1960). Tests of equality between sets of coefficients in two linear regressions. Econometrica, 28: 591–605.
Daly, J.A. and Andriole, S.J. (1979). Problems of applied monitoring and warning: illustrations from the Middle East. Jerusalem Journal of International Relations, 4: 31–56.
Daly, J.A. and Davies, T.R. (1978). The early warning and monitoring system: a progress report. Defense Advanced Research Projects Agency, Arlington, Virginia.
Druckman, D. (1977). Negotiation: Social Psychological Perspectives. Sage, Beverly Hills, California.
East, M. and Gregg, P. (1967). Factors influencing cooperation and conflict in the international system. International Studies Quarterly, 11: 244–269.
Eckhardt, W. and Azar, E.E. (1978). Major world cooperation events, 1945 to 1975. International Interactions, 5(2/3): 203–239.
Gamson, W. and Modigliani, A. (1971). Untangling the Cold War: A Strategy for Testing Rival Theories. Little Brown, Boston, Massachusetts.
Goldmann, K. (1972). Bipolarization and tension in international systems: a theoretical discussion. Cooperation and Conflict, 7: 37–63.
Goldmann, K. (1973). East–West tension in Europe 1946–1970: a conceptual analysis and a quantitative description. World Politics, 26(1): 106–125.
Goldmann, K. (1974). Tension and Detente in Bipolar Europe. Scandinavian University Books, Stockholm.
Goldmann, K. and Lagerkranz, J. (1977). Neither tension nor detente: East–West relations in Europe, 1971–1975. Cooperation and Conflict, 12: 251–264.
Hart, J. (1974). Structures of influence and cooperation–conflict. International Interactions, 1: 141–162.
Holsti, O.R. (1963). The value of international tension measurement. Journal of Conflict Resolution, 7: 608–617.
Holsti, O.R., North, R.C., and Brody, R.A. (1968). Perception and action in the 1914 crisis. In J.D. Singer (Editor), Quantitative International Politics: Insights and Evidence. Free Press, New York, pp. 123–158.
Hopple, G.W. (1978). The final report of the cross-national crisis indicators project. Defense Advanced Research Projects Agency, Arlington, Virginia.
Hopple, G.W., Rossa, P.J., and Wilkenfeld, J. (1979). Threat and foreign policy analysis: assessing the overt behavior of states in conflict. In P.J. McGowan and C.W. Kegley, Jr. (Editors), Sage International Yearbook of Foreign Policy Studies. Sage, Beverly Hills, California, pp. 19–53.
Howell, L.D. (1979). A comparative study of the WEIS and COPDAB data sets. Paper presented at the Annual Meeting of the International Studies Association, Toronto, Canada, March 24.
Hybel, A.R. and Robertson, D.B. (1978). Assessing the dynamic reaction of the USSR to American and Chinese actions and to its nuclear gap with the USA. International Interactions, 4(2/3): 125–154.
Jervis, R. (1978). Cooperation under the security dilemma. World Politics, 30(2): 167–214.
Kegley, C.W., Jr. (1973). A general empirical typology of foreign policy behavior. International Studies Series, Vol. 2. Sage, Beverly Hills, California.
Klingberg, F. (1952). The historical alternation of moods in the American foreign policy process. World Politics, 4(2): 239–273.
Koyck, L.M. (1954). Distributed Lags and Investment Analysis. North-Holland, Amsterdam.
Mahoney, R.B. (1977). European perceptions and East–West competition. Paper presented at the Annual Meeting of the International Studies Association, St. Louis, Missouri, March.
McClelland, C.A. and Hoggard, G.D. (1969). Conflict patterns in the interactions among nations. In J.N. Rosenau (Editor), International Politics and Foreign Policy. Free Press, New York, pp. 711–714.
Nerlove, M. (1958). Distributed lags and demand analysis. USDA Agricultural Handbook no. 141. US Department of Agriculture, Washington, D.C.
North, R.C., Holsti, O.R., Zaninovich, M.G., and Zinnes, D.A. (1963). Content Analysis. Northwestern University Press, Evanston, Illinois.

Park, T.W. and Ward, M.D. (1979). Petroleum-related foreign policy: analytic and empirical analysis of Iranian and Saudi behavior (1848–1974). Journal of Conflict Resolution, 23(1): 481–512.

Phillips, W.R. (1977). Prior behavior as an explanation of foreign policy. In M.A. East, S.A. Salmore, and C.F. Hermann (Editors), Why Nations Act: Theoretical Perspective for Comparative Foreign Policy Studies. Sage, Beverly Hills, California, pp. 161–173.

Rattinger, H. (1975). Armaments, detente, and bureaucracy: the case of the arms race in Europe. Journal of Conflict Resolution, 19(4): 571–595.

Richardson, L.F. (1960). Arms and Insecurity. Quadrangle, Chicago, Illinois.

Robertson, D.B. (1978). Perception as a modifying variable in macro-models of interstate behavior. Paper presented at the Annual Meeting of the International Studies Association, Washington, D.C., February 23.

Ruloff, D. (1975). The dynamics of conflict and cooperation between nations: a computer simulation and some results. Journal of Peace Research, 12(2): 109–121.

Rummel, R.J. (1966). A foreign conflict behavior code sheet. World Politics, 18(2): 283–296.

Rummel, R.J. (1971). A status field theory of international relations. Dimensionality of Nations Project, Research Report No. 55. University of Hawaii, Honolulu, Hawaii.

Rummel, R.J. (1972). US foreign relations: conflict, cooperation and attribute distances. In B.M. Russett (Editor), Peace, War, and Numbers. Sage, Beverly Hills, California, pp. 71–114.

Russett, B.M. (1967). International Relations and the International System: A Study in Political Ecology. Rand McNally, Chicago, Illinois.

Schlenker, B.R. and Goldman, H.J. (1978). Cooperators and competitors in conflict: a test of the triangle model. Journal of Conflict Resolution, 22(3): 393–411.

Sigler, J.H. (1971). Cooperation and conflict in United States–Soviet–Chinese relations, 1966–1971: a quantitative analysis. Peace Research Society Papers, 19: 105–128.

Sloan, T.J. (1973). A summary report on the development of the cooperation–conflict interaction scale for internation events data. The Review of Peace Sciences, 1: 1–19.

Soroos, M. (1977). Behavior between nations. Peace Research Reviews, 7(2): 1–107.

Taylor, T. (1978). Power politics. In T. Taylor (Editor), Approaches and Theory in International Relations. Longman, London, pp. 122–140.

Wilkenfeld, J., Hopple, G.W., and Rossa, P.J. (1979a). Determinants of conflict and cooperation in interstate relations. Paper presented at the World Congress of the International Political Science Association, 11th, Moscow, USSR, August 12–18.

Wilkenfeld, J., Hopple, G.W., and Rossa, P.J. (1979b). Indicators of conflict and cooperation in the interstate system, 1966–1970. In J.D. Singer and M.D. Wallace (Editors), To Augur Well: Early Warning Indicators of Interstate Conflict. Sage, Beverly Hills, California, pp. 109–152.

Zartman, I.W. (Editor) (1977). Journal of Conflict Resolution, 21(4) (Special Issue on Negotiation).

DISCUSSION

In reply to a question Ward *clarified that the model attempts to proceed from a certain basis, for example, resource constraints (or, at least, major adjustments of the resource dimension) which lead to increasing competitiveness between nations. This leads to tremendous strain not only amongst advanced nations but also in particular between advanced nations and the developing world to the extent that such economic strains may have the potential to lead to military conflicts, creating new patterns of conflict where none existed before and undermining mankind's capacity for dealing with the physical problems that have been discussed at the conference.*

Robinson *recalled that some possible changes (e.g. an increase of atmospheric* CO_2*) might harm some nations while benefiting others. Could his model reflect such a situ-*

ation? Ward *replied that in principle such possibilities could be dealt with. He added that several models have been developed to investigate the results of a reduction of military spending. A study based on the Bariloche model showed that there might even exist an "optimal" rate of disarmament: too small a rate would have no effect while too quick a disarmament might cause more harm than benefit, slowing down improvements in meeting basic needs for the larger part of mankind.*

EMPLOYMENT AND RELATED ECONOMIC IMPLICATIONS OF ENVIRONMENTAL ACTIVITIES IN A GLOBAL SCENARIO

S. Kuzmin
Employment and Development Department, International Labor Organization, 121 Geneva 22 (Switzerland)

1 SOME GENERAL REMARKS

1.1 Position of Environmental Activities in the Global Picture

As a starting point for incorporating the natural environment into global modeling it seems to be necessary to define clearly its place in the structure of contemporary world interrelationships and in the hierarchy of economic, social, political, and other subsystems composing the world entity. At least two alternatives are open here. One is to treat the environment as an integral though subordinate part of each and every kind of human activity, be it economics, social relations, culture, or education. Another is to look at the environment as a subsystem having its own system characteristics and peculiarities and therefore requiring special treatment. The first approach seems to be the most common and, at first glance, the most logical. However, the trouble is that under this approach the environment problem is sometimes viewed as something secondary (if not actually annoying) on the scale of priorities. As a result the resources allocated to environmental activities are often scarce; furthermore, since the resources are divided between numerous different sectors, there can easily be an overall loss of effectiveness in terms of economies of scale. In addition, the specific problems peculiar to environmental activities may also be lost, thus adding to the overall inefficiency of any particular piece of work in this field.

Another approach, namely, the gradual formation of environmental activities as a special "sector" of human activities would allow (1) the formulation of comprehensive strategies and policies relating to all parts and aspects of the natural environment, (2) the use of the technical equipment, manpower, skills, and experience gained in this field in the most comprehensive and hence most efficient way, and (3) attention to specific problems of and provisions for the environment such as the design of special equipment for environmental activities, the elaboration of planning, execution, and scheduling procedures, the training of manpower, and, above all, the provision of proper working conditions and quality of employment in this field.

Irrespective of what kind of approach is to be developed in the future, in a scenario for global modeling environmental activities can be purposefully grouped and specified as a sector of their own, which will allow for explicit comparisons and forecasting of the most important implications of developments in this field.

1.2 Comprehensive Study of Environmental Issues

There now seems to be an urgent need for a comprehensive approach to environmental issues and problems; i.e. the focus of studies and, subsequently, of a scenario with regard to the environment cannot be concentrated exclusively on pollution-abatement activities, as was very often previously the case. It is now recognized that, for example, the gradual erosion of the soil surface, natural damage (other than pollution) to water basins, the disappearance of valuable forests in favor of lower-grade ones, and general deforestation are also vitally important facets of the problem. However, they have not yet found their proper place in long-term global forecasts. (I felt obliged to put this consideration here, as a cornerstone for the whole approach to the environmental problem in a global scenario, though, of course, I am not the first to raise it (see, for example, McHale and McHale, 1948).)

The difficulty and at the same time the challenge for future studies is the need to make a transition from descriptive to operational terms while attempting to incorporate numerous environmental activities into the picture. (The translation of environmental aspects of development into explicit economic terms for the purposes of global forecasts is also completely in line with the needs of practical planning. Putting it roughly, the decision maker is not so much concerned with, say, the phenomena of salinization, as with the technical problem of desalinization costs, material resources involved, scheduling of expenditures, and possible gains; or, again, he is not so much concerned with the problem of soil loss as with the economics of soil rehabilitation, preservation, etc. Turning to this side of the environmental problem, one has the opportunity to choose and maneuver among various alternatives to solve the problem.) In the first place, a comprehensive and in-depth study on the economics of environment is on the agenda. A range of related economic indicators that is wider than that presently considered must emerge as a result of these studies and should include any employment-creating effects of environmental activities. Here we come to the next important point.

1.3 Investment in the Environment: the Economic Analogy

It seems that so far the environment problem has often been looked on mostly from the expenditure angle, with an inbuilt inclination to spend as little as possible. This may be partially a reflection of the centuries-old view of nature and natural resources as "free gifts".

The next logical step seems to be the explicit recognition of environment care and development as a normal and lasting field of activities like all the other "traditional" occupations of a society, in which a "reward" follows the expenditure of material and manpower inputs and not vice versa. The development of a planned systematic approach to environmental activities is already under way in the Soviet Union and other socialist countries (The Common Comprehensive Program of CMEA Countries' Cooperation in the Field of Environment Protection and Improvement and the Rational Use of Natural Resources which is described in "Prirodnye resursy i okruzhayuschaya sreda (Natural Resources and Environment)", No. 7, 1979, Moscow). In my opinion this is an overwhelming trend which will gradually extend throughout all regions of the world. This kind of environmental "philosophy" can also be developed and applied as a background to the environmental factors in any global scenario.

Accordingly a full account of positive and, possibly, negative effects of any environmental decisions and projections has to be explicitly inserted into scenario elaboration. The environmental solutions of contradictory economic and social problems should, then, be put on an equal footing with and be considered as alternatives to purely economic solutions. Let us illustrate this by simple examples.

The global problem of a rapid increase in food production, which, as is known, involves the rather contradictory problem of increasing the use of chemicals in order to raise the productivity of land and at the same time avoiding excessive pollution due to concentration of chemicals in soil and water, may have an alternative solution in the spending of more resources on the extension of arable areas, on the rehabilitation of arable lands that are now out of cultivation owing to salinization and desertification, etc.; i.e. the problem may have an environmental solution. Further, with the changing bias from excessive use of fertilizers and pesticides to the reclamation and development of new land areas there may be a gradual change in the geography of world food production in favor of, for example, tropical countries with their substantial resources of unused land. This by-product of an environmental solution could be, in the long run, a real contribution to the development efforts of these countries.

The rehabilitation of freshwater sources can also be no less (if not more) economically sound than the search for and investment in the development of new sources. An additional merit of an environmental solution in this and similar cases is that they do not increase the pressure on the earth's available resources.

The employment dimension may have a special significance in connection with environment and environmental activities. In addition, with the increasing of job opportunities (some or even many of them being "productive" in their essence) environmental activities, if sufficiently developed, can influence the structure and the reallocation of manpower, training and education, the migration of the labor force, and the established picture of rural–urban–rural movements of population. Employment–efficiency analysis can also be applied to this case.

2 ENVIRONMENTAL ACTIVITIES: DIMENSIONS AND A TENTATIVE CLASSIFICATION

For the purposes of building a framework for environmental policies and activities it seems to be appropriate to divide the problems related to the natural environment into three large groups.

(1) *Environment protection.* This group of problems relates to the current harmful or undesirable consequences of human activities on natural resources and ecological balances.

(2) *Environment preservation*. This refers to valuable and often unrestorable resources (forests, water basins, natural amenities, wildlife, etc.) that are in danger of being destroyed or exhausted in the near future as a direct or indirect result of human activities.

(3) *Environment development*. This embraces the problems and, henceforth, policy measures connected with the active influence of man on natural resources with the aim of (positively) transforming them.

2.1 Environment Protection

The seriousness of this problem in industrially developed countries is widely recognized. To give a rough idea of the dimensions let us examine some figures. The overall costs of pollution-control expenditures in the United States in 1972 amounted to about $19 billion, more than two-thirds of the total outlays consisting of costs imposed on business enterprises (together with government enterprises). (As Dorfman (1977) indicates, "all the costs, whatever their point of initial impact, are defrayed ultimately by households. The government expenditures are transmitted by increases in taxes and by reductions in governmental services of other sorts. Business expenditures are shifted to households primarily by increases in prices." This is a very important point to bear in mind when it comes to the social costs of pollution control and abatement.)

Air and water pollution problems are among the most pressing in developed industrial countries because, naturally, of the scale of industrial and urban development in these countries. In the United States, air and water pollution control and abatement costs amounted to 36% and 44% of all outlays, respectively. The removal of solid waste required another 20% of outlays (Cremeans, 1977).

Closely related to the problem of industrial water pollution is that of urban water pollution. Though the real dimensions of the problem are not known on the overall scale, one can guess that they must be tremendous.

One of the most difficult problems is that of water and soil pollution caused by the intensive use of some chemicals in agriculture. One of the practical approaches to this problem used in the United States is to limit the use of the strongest (and, at present, most effective) herbicides and pesticides, but this does not seem to solve the problem satisfactorily. The decisive answer will have to wait for further scientific research. Still, some preventive measures to avoid water pollution by the remnants of agricultural chemical inputs are being applied in many countries.

Not too much is known about the employment implications of the extending environmental activities in the field of environmental protection. On one estimate some 1 million persons were employed as a result of environmental regulations in the United States (ILO, 1976). In the Federal Republic of Germany, according to a preliminary report, "public and private spending on protection of the environment created about 200,000 jobs a year between 1975 and 1978" (ICFTU, 1979). The methodology behind these estimates is not known. To be fully aware of the employment implications one should take into account (1) the employment in industries directly engaged in the production of equipment for environmental activities, (2) multiple employment effects of this production on other industries and enterprises, delivery and servicing systems, etc.,

(3) those employed in operating this equipment, and (4) the manpower provisions for research, training, and management for environmental activities.

There is widespread opinion that the developing countries are not polluted to the extent that the developed countries are since their industrial wastes are much fewer, they cannot afford a high ratio of cars to people, they are less urbanized, and they use fewer fertilizers and other chemical ingredients in agriculture. Yet one must be conscious of the dangers of pollution which may strike these countries in the near future. Apart from the growth of industries and rapid industrialization, even now, "the poor economy may be more polluted because of the lack of funds to control the existing sources of pollution. For example, existing urban areas are frequently congested and have grown faster than the ability to control pollution sources. It would be reasonable to assume that rising levels of income in the less developed nations will bring rising levels of pollution unless economic development plans are such that adequate safeguards against pollution are provided" (Savage et al., 1974). This means that environment protection has to be put on the list of priorities in future plans, with all its implications for resources, employment, and the expansion of other sectors.

2.2 Environment Preservation

If the first problem deals mainly with the environment of human settlements and their extensions (e.g. rivers within the reach of conglomerations of people), this second problem is to a large extent that of a "natural environment".

The term "natural environment" basically includes the part of the earth's surface which has not yet entered into the sphere of human activities but at the same time is practically accessible for man and can be used (either the surface itself or natural resources located on and/or in it) for industrial exploitation. Some examples of what can be included in it are the area under national parks and reserves and the areas which have a protective function towards rivers and other water basins, soil erosion, etc. Whatever the reason to preserve these areas and to leave them untouched, their common feature is that they require a certain minimum amount of man's care and resource spending. Ignoring "the opportunities unrealized" in cases where particular sites are not used for industrial purposes, the preservation of these places itself requires certain material "sacrifices" from society. Sometimes these are direct expenses (keeping watch, reclamation works, current rehabilitation works, etc.); in other cases greater indirect costs are involved. For example, to reduce the excessively great deforestation in some places care should be taken to provide the local population with satisfactory substitutes for wood and other forest products.

The most common problem with the natural environment in developed economies seems to be in the choice of whether to give over the areas in question for industrial utilization (with all the possible negative consequences of this for the environment) or to preserve them untouched in view of the social recognition of their scientific, social, and human-welfare value etc. (Krutilla and Fisher, 1975).

It seems that in developing countries the problem in many cases is tougher and, in this sense, simpler. Leaving aside amenities of undoubted human and economic (tourist) value, there are in many developing countries parts of the environment that definitely require strict preservation measures if major natural disasters and other great economic catastrophes are to be avoided.

Some facts that are mentioned by Eckholm (1976) seem to be rather typical. For example, in Indonesia:

> "as the clearing of hillsides by farmers accelerates, so does the load of silt that clogs Java's indispensable irrigation systems and destroys the usefulness of its reservoirs.
>
> As desperate farmers, aided by wood merchants and firewood gatherers, clear more and more hills in the Himalayas, the incidence and severity of floods in the lowlands below is rising. The lives of 20 million people in India are directly disrupted by flooding in the average year, and when the rains are particularly heavy, as many as 50 million people are so affected. Monsoon rains rush off tree-shorn slopes, and the increased load of silt carried by the Indian subcontinent's rivers raises their beds so that annual floodwaters are spread outward more rapidly . . . . Flood problems are similarly accentuated by hillside deforestation in Eastern India, Pakistan, Thailand, the Philippines, Indonesia, Malaysia, Nigeria, Tanzania, and many other countries. *Though hundreds of millions of dollars are spent around the world each year on engineering projects like dams and embankments to control floods, engineering 'solutions' can address only the effects, not the causes, of basic ecological imbalances*". (Eckholm, 1976, p. 41; the emphasis is mine)

It can be added that "too-frequent clearing in the humid tropics reduces precious high forests to thick shrubbery of little economic value, in some cases, to tough grasslands difficult and costly to reclaim for farms or any other economic use. The loss of high forests to the tenacious grass *Imperata cylindrica* following temporary cultivation is a major problem in the Philippines, Indonesia, and parts of Africa" (Eckholm, 1976, p. 42).

The scales of deforestation are enormous and threatening. Thus "in Asia, for example, the Food and Agricultural Organization (FAO) estimates that 8.5 million hectares of forest are cleared annually by shifting cultivators; a woodland the size of Portugal is cleared *each year*. An estimated 5–10 million hectares are cleared annually for agriculture in Latin America, mostly for temporary farming" (Eckholm 1976, p. 42).

All this is of course only a part of the available evidence of the fact that the preservation problem (including not only problems of forest lands but also the preservation of water basins, the prevention of soil erosion in open spaces, etc.) has quite a high priority in developing countries. In many cases it is the root of many other problems for which an "engineering solution" is often sought.

For the reduction of costs this group of environmental issues suggests, it seems, a favorable ground for the combination of nationwide efforts with local activities. A proper "division of labor" is of course needed in this case; e.g. the government caring about plant nurseries, technical advice, the launching of "intermediate-tools" manufacturing, the institutional network, etc., and local communities supplying labor and some local inputs.

There is also the possibility of choosing between labor-intensive and capital-intensive techniques in these activities (reforestation, fire-preventing trench digging, etc.). (For the approximate appraisal of the development and employment effects of these undertakings one can assume that the effects (especially employment effects) may be parallel to those of labor-intensive road-construction projects which have already proved their vitality and efficiency together with high labor-absorbing effects in a number of developing countries (see, for example, Allal and Edmonds, 1977).) In addition, local auxiliary activities (the production of tools, transportation, plant nursing, etc.) may develop as a consequence of the more major project.

Undoubtedly, this type of environmental activity can be a source of a significant demand for manpower if some necessary conditions are observed (sufficiently strong political will, a proper combination of the national and local levels, and, of course, some minimum capital outlays to launch the whole venture).

2.3 Environmental Development

This problem (and the corresponding type of activities) in many respects borders on the previous one. The difference, sometimes only partially noticed, is, firstly, that preservation activities, whatever their extent, are aimed at supporting the existing conditions of natural resources while development means opening up and extending new economic resources in, at the very least, a harmless way for nature; in this sense, preservation of the environment can be listed as "current-account" activity while development can be classed as "capital-account" activity. Secondly, preservation activities conventionally deal with space which is already within the sphere of active human influence while development activities often extend to areas basically untouched by man such as deserts, great marshes, and remote forest areas.

The point is that regardless of the seemingly impetuous activities of man on the earth many places as yet remain virtually untouched. However, lack of human care in some places may bring about great harm (e.g. the further or accelerated destruction of such areas). The following are some brief examples: (1) forestry resources lost because of overaging, rotting, fire, uncontrolled floods, etc.; (2) rivers, changing their course each 3–5 years, narrowing, destroying their banks, and finally becoming completely useless from the economic point of view; (3) lakes and other water basins, disappearing under vegetation or becoming swamps; (5) deserts advancing onto cultivated lands; (6) uncontrolled floods, salinization absorbing the arable soils; (7) oceanic coastline erosion reducing useful land area.

Being an overall world problem, environmental development of course impinges on the developing nations, and may do so increasingly in the near future, in the most painful way, further decreasing their already-scarce resources. In this sense, environmental development, widely defined, coincides with economic development. Let us again give some examples.

(1) A national program of afforestation. Together with environmental and social effects, some of which cannot be felt immediately, such a program could support the development of forest-based industries (including export-oriented ones), increase employment in households and in small-scale and cottage industries, and help to solve one particular problem of developing countries, namely the provision of households with sufficient cheap fuel for their private needs (in some countries it could save manure that is now burnt in the house fires).

(2) Reclamation and improvement of lands, including work on soil reclamation and preservation together with efforts to make these lands suitable for human settlements.

(3) Projects aimed at the preservation of existing water basins (by fixing the banks both by embankment construction and afforestation, by preventing the basins becoming overgrown with grass, etc.) and the prevention of floods. Apart from the direct environmental effect of these measures, they could save additional water resources for economic use.

Programs of reforestation may include restorative planting on recently deforested lands, afforestation of areas historically for a long period without forests and vegetation, the creation of shelter belts in areas suffering from wind erosion, and the replacement of bushes and low-grade forests by high-grade forests. Part of such work would be designed to help solve the third problem listed earlier, namely the preservation of rivers and water basins. The scales of such projects can be really tremendous. Let us give an example of the last task (i.e. the replacement of nonvaluable woods by high-value woods). In the Philippines, "forestland accounts for about 57%, or 17 million hectares, of a total land area of 30 million hectares. Proclaimed timberland is a little more than 9 million hectares, and the difference of 8 million hectares has yet to be classified as to their final use, either for timber [or for other purposes]. The most certain assurance of continued harvests is timber stand improvement on a massive scale, which *would require millions of man hours* for liberation cutting, cleaning, girdling, thinning, and other cultural practices. Timber stand improvement is in fact a major pillar of the government's forest rehabilitation efforts . . ." (ILO 1977, p. 28; the emphasis is mine). The joint study of the Philippine Bureau of Forest Development, the International Labor Organization, and the Government of Finland just cited is very firm in its findings on the significant employment implications of reforestation programs. (This is despite the fact that at present direct employment in forestry is rather low: "total employment in logging and forestry (not including the wood-processing plants) does not exceed 100 thousand persons, and is more likely a half to two-thirds that number" (ILO, 1977, p. 16).) The conclusions of the study appear particularly sound if labor-intensive technologies are used, which seems feasible. "In silviculture, reforestation, forest protection, nursery work, and some parts of logging and forest road construction, the creation of jobs does not require large amounts of complementary fixed capital. With the exception of some highly skilled positions in logging, most of these jobs can be filled by workers without machine skills. The jobs are frequently in remote regions where alternative sources of wage employment are nonexistent" (ILO, 1977, p. 15).

Indirect employment creation should also be taken into account. According to the same study, "forestry has strong backward linkages to manufacturers and suppliers of equipment and hand tools, many of which could be provided by domestic sources. It also has strong forward linkages to potentially labor-intensive rural manufacturing, e.g. sawmills, wood-carving shops, handicraft shops, and furniture manufacturers. In the USA and Europe the employment multiplier in related sectors per unit of employment in forestry is between six and seven. There is little risk in supposing that a multiplicative effect similar or greater in magnitude applies in most developing countries, where the wood-processing industries are generally less highly mechanized" (ILO, 1977, pp. 15, 16, where reference is made to Sartorius and Henle, 1968).

Similarly the improvement of potentially arable land has both economic and environmental qualities. The incorporation of new land into the agricultural turnover is of course an urgent economic task in many developing countries. At the same time there are undoubted environmental gains, consisting in particular of the prevention of further irreversible destruction of the area concerned, the protective influence of improved areas on surrounding natural resources, the preservation of the soil waters, the prevention of dust storms, etc.

Certainly, the employment opportunities emerging from these projects should in every case be thoroughly checked against other economic implications. One can guess, however, that under the conditions of developing countries in many cases a reasonable combination of labor absorption and economic efficiency can be found.

3 REFLECTIONS OF ENVIRONMENTAL ACTIVITIES IN A GLOBAL SCENARIO

3.1 Levels of Implementation of Environmental Programs

Conventionally, environmental programs, whatever they are, have been carried out mostly at the national level and by nationwide efforts. In recent years, however, there has been a growing feeling that this is not enough, especially in less developed countries. On the one hand many environmental problems involve more than one country and require too great an expenditure to be the responsibility of one state; these situations clearly call for international cooperation. On the other hand some environmental programs, being the responsibility of a central authority, have not had a sufficient "trickle-down" effect, in the sense that local levels have not been involved deeply enough in active participation in these programs and, in return, have not gained very much from them in terms of everyday needs.

The international aspect (regional and subregional projects) is now gradually entering the focus of attention of both national governments and international bodies. The spread of activities involving several countries now absorbs different sides of the environment problem and different types of the activities described earlier. Still, many environmental protection and improvement projects remain in the domain of the national level, especially when they are identified with national sovereignty over natural resources.

The local level of environmental activities is the level that has yet to be more thoroughly studied and framed within a comprehensive program of environment care.

Generally the local level of participation in development efforts, which to a considerable extent has been underestimated in many past strategies, seems nowadays to have a real chance of becoming one of the vital elements of the new international development strategy for the 1980s and 1990s.

"Grass-roots" environmental activities may become, in this connection and in a proper social framework, a substantial material expression of local participation.

(At the village level many environmental projects are directly related to improving agricultural performance and providing the producer with more productive assets and a gainful job. Yet, archaic social structures and the all-dominating role of those in power within villages are quite often a strong impediment to the development of local activities, which should involve all villagers. As Dumont (1975) puts it, "there are so many useful things to do in every village of Bangladesh, such as to improve water control (irrigation, drainage, floods control). And there are so many people without any work for at least 3 or 4 and even 6 months every year! The landless and the too-small farmers, who represent together 40–50% of the rural population, are in such a situation. How can a link be found between the workless and work? Land reform, land taxes, and many such solutions could be found, if a political will were to exist, but the urban privileged minority have the political power, while at the village level the moneylenders and landowners are their main support.")

To summarize, for the purposes of global scenario construction all three levels of environmental activities have to be identified and incorporated into the global projections. Some possible devices for achieving this are discussed in the following.

3.2 Cost–Benefit Analysis

The difficulty is the scarcity of convincing evidence that environmental activities are an economically gainful way of spending money and human resources. The main reason for this is that the economic effects of such spending lag a long way behind those of the "usual" types of investment. It therefore seems to be an almost impossible task to apply the conventional devices of cost–benefit analysis to environmental activities. Still, this technique cannot be abandoned since for some fields at least and with some special reservations it may prove useful. Firstly, some of these activities can be compared with other long-term activities of a society (e.g. infrastructural projects). Secondly, in some other cases the effects of environmental activities are more evident for the purposes of comparative analysis if the works are carried out continuously and the society begins to reap each year the fruits of previous environmental activities. (In Afghan villages, for example, annual renewed tree planting has become an important source of fuel and wood for construction.) Thirdly, there are always additional returns from environmental activities which cannot be neglected.

As a first approximation, the costs and benefits from environmental activities can be grouped in the following way.

Costs: (1) the financial costs of a project; (2) the foreign-exchange component of the total costs; (3) "missed opportunities" because of noninvestment in other more profitable ventures; (4) training expenses for skilled personnel and management.

Benefits: (1) material additions to welfare including the preservation or increase of valuable natural resources, the improvement and increase of productive assets, and the preservation or improvement of existing amenities; (2) increase in amounts of some exportable materials (e.g. wood); (3) the extension of tourism industries; (4) the creation of additional employment.

Both costs and benefits may vary depending on the type of environmental activity and the conditions in a particular country. It should be stressed, however, that usually there is room for reducing the costs by substituting deficit resources by less-deficit ones, capital-intensive techniques by labor-intensive ones, etc. In contrast some of the benefits listed are almost immediate, especially if achieved at the microlevel (e.g. availability of additional fresh water for personal use and for irrigation and new plots of land for cultivation and new grasslands as a result of local environment amelioration efforts). Some other benefits of a longer-term nature can be evaluated, as has been mentioned, along the lines of other long-term undertakings of a society (as a "tax" or "investment" that any society has to pay in order to improve its future development prospects); the positive effects of these benefits on the fulfillment of, say, local-level environmental tasks result in the receipt of additional microeffects which increase the total attractiveness of the particular project.

Any efforts to translate these effects into a long-term global scenario immediately encounter at least two difficulties. Firstly, there is a lack of statistical data, which in the case of the economics of the environment are more than scarce and sometimes non-existent. This difficulty cannot of course be remedied on a short time scale. For the time being we have to work with what data are available, though some efforts can be made to obtain additional information through ongoing surveys (e.g. the household survey) started by the United Nations system.

The second difficulty is the absence of an adequate methodological tool with which to map rather nonhomogeneous data on the subject into a few key numerical values.

3.3 "Modules of Transition"

To solve the difficulty one can imagine the creation of a set of "modules of transition". These are coefficients for the translation of the effects of policies in one field into related effects in another field. For example, a rise in the productivity of labor can be presented as a function of a general rise in the cultural and educational level of a population, and expenditures on education can then be expressed in terms of the rates of growth of productivity. The coefficient relating one to the other will be a module of transition.

In the next section we give examples of some possible modules as applied to our particular topic.

3.4 Preservation, Reclamation, and Development of the Soil Surface

The multiplicity of projects and their results has to be reduced to a few economic effects which are explicit and which can be expressed in numerical terms. On the local level the participation of the peasantry and agricultural workers in the various activities may result in a rise in the cropping intensity of already-cultivated lands, the introduction into the agricultural turnover of new plots of arable lands and grasslands, and, overall, more intensive use of land resources. For operational simplicity all these effects may be expressed as a single indicator (e.g. as an addition to the harvested area), with other variables unchanged.

The same activities at the national level (the extension of arable lands through irrigation, environmental amelioration, the halting of land erosion, desalinization, prevention of floods, etc.) can, by analogy, be reduced to one or two indicators (e.g. to the total increase in arable area suitable for cultivation). Summarized at the regional or international levels, these figures will give some basis for constructive speculations as to the possibility of increasing food production, providing additional employment, etc.

Numerous environmental projects related to water resources can also be reduced by their final results either to the provision of additional water for agriculture and household consumption or to the reduction (through the protection of existing water resources) of the initially projected costs of recovery and delivery systems for the additional sources of fresh water. (One estimate states that by the year 1990 the costs of providing the population of the earth with fresh water will reach about US$9 billion a year (Anon., 1977). Yet, this may be a rather moderate estimate if one takes into account the rates of pollution and the increasing demand for water for irrigation and other agricultural purposes.)

The estimates for the scenario which are to be made on the basis of translational modules will of course be fairly approximate because of the high level of aggregation and sometimes the lack of important statistics. Still, this is better than nothing since the activities under consideration and their possible effects on the world economy are realities of future development which cannot be ignored. Once these rough estimates have been made and incorporated into a scenario further improvements will be possible through the collection of more precise evidence and the extension of the statistical coverage of the indicator concerned. (For example, it seems possible as a first approximation to make a plausible estimate of obtaining 5–10% of additional cultivable land as a result of extended local activities on land reclamation, small-dam construction, clearing, etc.) The employment and other related economic implications of various environmental activities can then be studied in close connection with the implications of various activities in other sectors of the world economy.

REFERENCES

Allal, M. and Edmonds, G.A. (in collaboration with A.S. Bhalla) (1977). Manual on the Planning of Labor-intensive Road Construction. International Labor Organization, Geneva, Switzerland.

Anon. (1977). The Economist, February 5, p. 43.

Cremeans, J.E. (1977). Conceptual and statistical issues in developing environmental measures – recent US experience. The Review of Income and Wealth. Income and Wealth Series, No. 2, June, Table I.

Dorfman, R. (1977). Incidence of the benefits and costs of environmental programs. American Economic Review, 6(1): 333.

Dumont, R. (1975). World priority number one: population and subsistence. In B. Pregel, H. Lasswell, and J. McHale (Editors), Environment and Society in Transition: World Priorities. New York, p. 148.

Eckholm, E.P. (1976). Losing Ground, Environment Stress and World Food Prospects. W.W. Norton, New York.

ICFTU (1979). Protection of the environment creates jobs. International Trade Union News, June 1. International Conference of Free Trade Unions, p. 6.

ILO (1976). Social and Labor Bulletin, No. 4, December. International Labor Organization, Geneva, Switzerland, p. 348.

ILO (1977). World Employment Program, Appropriate Technology in Philippine Forestry. International Labor Organization, Geneva, Switzerland.

Krutilla, J.V. and Fisher, A.C. (1975). The Economics of Natural Environment, Studies in the Valuation of Commodity and Amenity Resources. Johns Hopkins University Press, Baltimore, Maryland, p. 80 et seq.

McHale, J. and McHale, M.C. (1948). Basic Human Needs: a Framework for Action. Report to the United Nations Environment Program, Brunswick, New Jersey.

Sartorius, P. and Henle, H. (1968). Forestry and Economic Development. New York, p. 271.

Savage, et al. (1974). The Economics of Environmental Improvement. Houghton Mifflin, Boston, Massachusetts.

GLOBAL MODELING ACTIVITIES AT THE SCIENCE CENTER BERLIN

Stuart A. Bremer
International Institute for Comparative Social Research, Science Center Berlin, Steinplatz 2, D-1000 Berlin (West)

To those who feel that global modeling is dead, or at least fading fast, I would like to report that global modeling is alive and doing relatively well at the Science Center in West Berlin, and in the next few pages I would like to document this bill of health. However, first a few words about the relatively young Science Center Berlin may be in order.

The Science Center Berlin (Wissenschaftszentrum Berlin) was founded some ten years ago in order to foster basic and applied research in the social sciences; this is a focus which makes it rather unique in a world where governments are lavish in their support of the physical sciences and sparing in their support of the social sciences. In this particular case, however, the governments of the Federal Republic of Germany and West Berlin decided to encourage social science research and to provide the financial means for the research which is discussed here.

The first of the three institutes which presently comprise the Science Center, the International Institute of Management, concerns itself with the economic problems of industrialized societies. The second institute to be founded, the International Institute for Environment and Society, is as the name implies chiefly concerned with environmental problems. The institute to which I belong, the International Institute for Comparative Social Research, is the youngest of the three and has the broadest research mandate. Our task is to anticipate and evaluate stresses and strains which governments are likely to confront over the next few decades. One part of the Institute, under codirector Frieder Naschold, focuses chiefly on the European and, more specifically, German context, while the other part of the Institute, under codirector Karl W. Deutsch, has a more global and longer-term orientation; it is within this latter part of the Institute that I work.

One of the main themes of the research that we are conducting aims at the employment of global models to anticipate future stresses and strains on governments in the next quarter of a century and to evaluate strategies for coping with these. Initially our principal undertaking was the evaluation of existing global models. In two cases (World 3 and the Bariloche models) we were able to implement the models and to conduct experiments with them. We have, for example, examined the behavior of World 3 under alternative assumptions on rates of technological advance. In another instance less optimistic housing-cost assumptions were introduced into the Bariloche model. In a third study the demographic submodels of World 3 and the Bariloche model were analyzed side by side. Other models (e.g. the Systems Analysis Research Unit Model (SARUM), the Mesarovic–Pestel model, and the Model of International Relations in Agriculture (MOIRA)) have been examined in terms of their structural characteristics and verisimilitude, and many of these results can be found in Bremer et al. (1980).

These studies led us to an appreciation of the strengths and weaknesses of the various models and provided us with a point of departure for our own modeling work. The models developed so far are essentially economic models, occasionally coupled to demographic models. Few would consider this an unfair assessment or an earth-shaking conclusion, but in our view the models were incapable of dealing with problems which were as important, if not more important, than those with which they were designed to deal. We thought, in short, that it was feasible to construct a model which would bring the "political dimension" into global models. Shortly it will become clearer precisely what we mean by this but at this stage let me summarize our intentions as the introduction of some macropolitical factors into the decision structures of our models and the tracing out of some of the macropolitical consequences of essentially nonpolitical developments.

The direction of our own work is evident when five essential ways in which our global model will differ from all others are considered. First, and perhaps most important, we have selected the nation-state as our central acting unit since we do not believe that it is possible to represent global dynamics adequately without the tugging and pulling – sometimes together, sometimes apart – of nations. Critics of World 3 were virtually unanimous in their condemnation of its representation of the world as one unit. Subsequent models, with the notable exception of MOIRA, have attempted to deal with this problem by dividing the world into regions. The decisions as to which nations are assigned to which regions seem to be based primarily on a vague mixture of geographic and economic considerations. Hence we often find the countries of Eastern Europe grouped together with the Soviet Union. However, we also find on occasion that nations such as Israel, South Africa, and Australia are assigned to the same region. Not being an economist I can only question, not judge, the reasonableness of treating such groupings of nations as if they were one economic unit but from a political standpoint such groupings make little or no sense and, more importantly, define away an essential (perhaps *the* essential) determining factor of the world's predicament: i.e. the world is composed of more than 150 squabbling decision-making centers and not a dozen integrated economic entities uniformly and dutifully obeying the laws of supply and demand. Whether this latter situation would be an improvement over the present one is not a matter about which I wish to speculate here but rather I merely point out that the world would have to undergo a great deal of social, political, and economic change in order to move from one structure to the other.

One of the existing global models, MOIRA, did not divide the world into regions but instead the designers represented it as composed of over 100 separate food-producing and food-consuming units. They were able to do this without being overwhelmed with complexity by restricting their focus to essentially one aspect of the world problématique – food. Their model is thus broad in a way that regional models are not but it is thin with respect to sectoral coverage. For global modelers the tradeoff between sectoral differentiation and regional disaggregation is for all practical purposes impossible to avoid. Given that we too envisage a multisectoral model and that, at the same time, we feel strongly about using nations rather than groups of nations as our central acting units, one may well ask what feats of magic we propose to avoid the issue.

The "solution" to the problem that I have been discussing lies, I think, in conceptualizing the regional disaggregation of a model as a variable rather than a constant. That is, we must develop models which allow us to change the number and identity of behavioral entities whose behavior we wish to simulate without having to structurally alter (i.e. recompile in the computer sense) the model. An ability to exogenously respecify the size and composition of the system being modeled would be useful from a practical as well as a theoretical standpoint. On the practical side it would allow us to expand or contract the model in response to variations in computing power and manpower, and on the theoretical side it would enable us to change the resolving power or, to use another optical allusion, the depth of field of the macroscope that we have all been trying to construct.

Few, I think, would question the desirability of such a capability but many may be skeptical as to its achievement. This depends on our ability to develop "genotypic" submodels, i.e. structural representations of a "typical" market economy and a "typical" centrally planned economy or a "typical" peoples' democracy and a "typical" western democracy. These genotypes, which would serve as the basic building blocks of the system, must at the same time be flexible enough in form to allow for some tailoring and customizing if we are not to be reduced to representing only the crudest of differences between nations. Apart from their essential structural differences, as represented by the notion of different genotypes, nations differ from one another with respect to their behavioral propensities, which would be reflected in different parameter values, and their historical–developmental contexts, which are generally represented by the initial values of their state variables or starting conditions. In reality the distinction between behavioral propensities and structural characteristics becomes blurred when we allow parameters to assume a zero value.

No matter how optimistic one is about the effectiveness of the genotype strategy one must concede that some loss of verisimilitude will occur. This is essentially the tradeoff that is being substituted for the one discussed earlier, and whether this trading of tradeoffs will turn out to be profitable can only be judged in the long run. Our concrete objective at this point is to represent 25 of the world's most significant and active nations as separate decision-making goal-seeking entities within our global model and to treat the rest of the world in a largely residual way.

A second major way in which our work departs from the work of others concerns the role which we assign to government. Most global models, if they include governments at all, treat them in a residual fashion not unlike the way in which they are commonly represented in national econometric models, i.e. as a purchaser of goods and services obeying exogenously determined or predetermined rules. The government is there because the great gross national product identity requires it but it is not represented as a goal-seeking decision-making unit.

In our view the behavior of national governments is important (since they provide whatever society-wide steering capabilities that nations may have) and more predictable at the macrolevel than has been heretofore assumed by global modelers. Certainly recent work in the resurgent field of political economy supports the notion that government spending, taxation, and borrowing is responsive to national and international developments. Our approach then is to conceptualize governments as seeking to achieve or maintain certain levels of national security, economic well-being, and political stability in the face of fluctuating internal and external conditions. In addition, we rely heavily on Herbert Simon's notions of characterizing or describing the behavior of a decision-making unit *as if* it were following a relatively simple set of decision rules.

Although enhancing the role of government should enable us to introduce a substantial number of political questions and considerations we are not so naive as to believe that we can represent all or even a substantial portion of the features of day-to-day political reality. Just as macroeconomists do not concern themselves with the daily behavior of individual producers and consumers so we are not primarily concerned with the behavior of individual voters or politicians. We consider individual policies as manifestations of a more general problem-solving approach and specific events as indicators of underlying fluctuating tendencies. Hence I do not foresee that we will be able to (nor do we seek to) predict the political fortunes, for example, of specific leaders or parties. What we do think is feasible and desirable is a model which permits us to study and illuminate the conditions that are likely to increase significantly the stresses and strains on governments, to frustrate their coping mechanisms, and to produce pressures for major political change.

A third point of departure which distinguishes our work from that of others is the assumption that economic outcomes have political consequences and that these consequences can be anticipated to a significant extent. We want our model to be able to spell out for us these larger consequences in order to make explicit some of what is implicitly contained in other global models.

Consider for a moment the subject of unemployment. From an economic perspective high unemployment is undesirable because it reflects underutilization of a factor of production, and the underutilization of a factor of production may be among the seven deadly sins of economics. Be that as it may, I think it is reasonable to assert that governments are attentive to, and attempt to control, unemployment not so much out of consideration for economic efficiency as consideration for political stability. Sporadic and localized unemployment makes people unhappy; widespread and persistent joblessness tends to make people angry and frustrated, a condition conducive to mass violence. It is precisely this type of linkage that we are attempting to formulate and which we plan to include in the model.

Viewed from this perspective the futures outlined by various global models, which only promise economic dislocations and/or disasters, are underestimations of the deprivation and suffering that we are likely to confront in moving into and through the 21st century. In informal conversations global modelers concede that their models are incomplete in the manner that I have outlined in the foregoing but they counter that the type of thing that I have been discussing cannot be modeled. I believe that a perusal of the empirically based political science work done over the last ten years or so would not lend support to this contention. At least enough work has been done to demonstrate that it is possible to model the linkages between economic outcomes and political consequences. Having made the assertion that it is possible to factor political phenomena into global models let me step back slightly and concede that the form and precision of many of the "predictions" in the political realm are likely to differ from those conventionally made by global models. I can foresee, for example, that we will have to be content with forecasting the probabilities of certain major events occurring rather than the events themselves. Furthermore, I expect that the error margins in the political area are likely to be larger than those which global modelers think that they have now. This should not in my opinion be construed as support for ignoring political phenomena altogether since models which exclude such factors inherently have larger error margins than those which include them.

A fourth way in which our model will differ from all but one of the current global models is in the degree to which international economic transactions are influenced by noneconomic factors. We reject the notion that flows of goods and services within the international system are governed solely by the laws of supply and demand and feel that a representation of such flows which does not take into account nonmarket factors is not likely to give us an accurate picture of the international economic scene. Furthermore, a model of trade flows, for example, which does not allow for trade restrictions or liberalizations based on political considerations does not offer us much of a vehicle for undertaking experiments on the possible impact of such factors in the future. The only global model which currently allows for the operation of nonmarket factors in international trade flows is SARUM, which relies on a set of trade-bias coefficients.

We would like to go beyond this in modeling international flows of trade, aid, and, perhaps, capital by endogenizing those political considerations which influence these flows. This means in turn that we must be able to represent these flows at the dyadic level; i.e. we cannot rely on the pool concept of trade where all national exports go into and all national imports are drawn from an undifferentiated pool. This conceptualization assumes that the destination of a flow in the international system is independent of its origin and vice versa; although this may be a convenient approximation it falls short of what we think can be achieved.

This is not the place to give detailed information about how we plan to model these flows and the factors that influence them but I should say something about the commodity breakdown that we are using at the moment. We distinguish between six different types of goods: food, consumer goods, capital goods, energy resources, non-energy resources, and armaments. The inclusion of the last category indicates in another way how our approach differs from others and reflects our feeling that, although the arms trade may be relatively small in comparison to world trade, it is very important politically and can produce serious long-run consequences of which we should be made aware. Modest as these ambitions may appear to be, we are aware of a number of factors which may prevent us from realizing all of this and we recognize that it may be necessary to settle for a simpler representation at some future time.

The final aspect that I want to discuss and which differentiates our modeling group from others is the inclusion of international conflict in our agenda of concerns. We believe that issues pertaining to war and peace are as important as those pertaining to the quantity and quality of life since developments in the former area can dramatically affect the latter. We certainly cannot rule out international violence as one of the strategies to which governments may resort when confronted by the types of problems that other global models have been foretelling. The tendency to export problems and to pursue unilateral solutions remains strong in today's nations, and I see little reason for optimism about the likelihood of reform. If for no other reason than that nations devote a substantial share of their resources to the establishment and maintenance of instruments of violence, we should be concerned about this area in the future and our models should reflect this concern.

We are attempting to develop submodels which spell out the consequences of certain economic, social, and political developments for international tensions and conflict so that our model can ultimately say something about this set of concerns. Although much path-breaking work has been done in the modeling of international conflict processes over the last decade, a great deal of work remains. Accordingly our immediate ambitions in this area are modest. We do not envisage at this time that anything like the ability to predict precisely when and where large-scale international violence will break out will emerge from our work. Nor do we intend to model the day-to-day diplomatic bickering and maneuvers which dominate the press. What we seek at this stage is a submodel which will enable us to obtain a broader, albeit vague, picture of what might happen in the future.

Up to this point I have spoken in terms of approaches, directions, plans, aspirations, and other such abstractions; I should at this point report on some of the more concrete aspects of our work in the global modeling area. We began our work by carefully examining and thoroughly criticizing a model which I developed some years ago. This model (the Simulated International ProcessER (SIPER)) grew out of the simulation work carried out at Northwestern University under the direction of Harold Guetzkow (Bremer, 1977). Our review of SIPER revealed many things about the model that we liked and many that we disliked, and we set out to extend and revise it. Our first progress report was delivered at the World Congress of the International Political Science Association in Moscow in August, 1979 (Bremer et al., 1979). As that report reveals, we have focused so far on government resource allocation, domestic political stability, international trade, and international conflict. Other studies which have been completed and which are available from us deal with defense expenditures (Cusack and Nincic, 1979; Bremer and Cusack, 1980; Cusack and Ward, 1980), international economic relations (Pollins, 1980a, b), conflict involvement (Yamamoto and Bremer, 1978; Bremer, 1978a), and general global modeling questions (Alker, 1977; Bremer, 1978b). Our next reports will deal with the genotypic macroeconomic and macropolitical structures that we are designing.

REFERENCES

Alker, H.R., Jr. (1977). Global modeling alternatives. PV/77-2. Science Center Berlin, West Berlin.

Bremer, S. (1977). Simulated Worlds. A Computer Model of National Decision Making. Princeton University Press, Princeton, New Jersey.

Bremer, S. (1978a). The powerful and the war prone: relative national capability and war experience, 1820–1965. PV/78-20. Science Center Berlin, West Berlin.

Bremer, S. (1978b). Some observations on the testing of global models. PV/78-21. Science Center Berlin, West Berlin.

Bremer, S. and Cusack, T. (1980). Anticipation and arms accumulation: a simulation study of the impact of forecasting on arms races. IIVG/dp 80-106. Science Center Berlin, West Berlin.

Bremer, S., Cusack, T.R., Pollins, B.M., and Widmaier, U. (1979). Cumulative efforts in sociopolitical global modeling: results from a new look at SIPER. IIVG/dp 79-3. Science Center Berlin, West Berlin.

Bremer, S., Kappel, R., Otto, P., Weck, H., and Widmaier, U. (1980). Weltmodellstudien: Wachstumsprobleme und Lösungsmöglichkeiten. Athenäum, Königstein–Taunus.

Cusack, T. (1980). An assessment of research on arms accumulation along with some suggested guidelines. IIVG/dp 80-105, Science Center Berlin, West Berlin.

Cusack, T. and Nincic, M. (1979). The political economy of US military spending. IIVG/pre 79-4. Science Center Berlin, West Berlin.

Cusack, T. and Ward, M. (1980). Arms in the superpower triad: forecasts to the year 1990. IIVG/dp 80-108. Science Center Berlin, West Berlin.

Pollins, B. (1980a). A survey of fourteen formal models of international trade. IIVG/pre 80-108. Science Center Berlin, West Berlin.

Pollins, B. (1980b). Technology, international political economy and international relations theory. IIVG/dp 78-8. Science Center Berlin, West Berlin.

Yamamoto, Y. and Bremer, S. (1978). Wider wars and restless nights: major power intervention in ongoing wars, 1816–1965. PV/78-11. Science Center Berlin, West Berlin.

DISCUSSION

Norse *raised the question to what extent it makes sense to endogenize government choices. Direct and indirect taxation have quite different effects on employment and on inflation.* Bremer *replied that from a more macro point of view it is essentially a question of what amount of resources a government can extract from society, and at what rate; the question of direct versus indirect taxation may have short-term economic consequences which from an economist's standpoint are important but from the more macro standpoint turn out to be less important.*

Steger *and* Cusack *held that governments in their actions will certainly react to changes in economic conditions as well as to changes in public opinion concerning economic conditions.* Bremer *cited work done by Bruno Frey on such relationships; yet, again from a more macro point of view, it could be safely stated that the basic mechanisms of government remain the same, sufficiently so for it to be possible to endogenize government behavior.* Roberts *seconded this view: people ascending in the government hierarchy are amazed to find how freedom of action drastically disappears the higher they rise. The President of the United States had practically no power to implement his energy policy; changes can only come about if they are based on change in public attitude. Hence it is not so much government policy that needs to be reflected in political models as public attitude. In reply* Bremer *expressed doubts whether public attitudes actually change sufficiently quickly; attitudes prove to be surprisingly stable over time. Instead of modeling attitudes it might be preferable to represent the behavioral consequences of certain socio-political and/or economic configurations, e.g. nuclear power generation. Just because the constraints placed on government actors are so powerful that they restrict severely freedom of choice, attitudes as they are manifested from day to day are not to be considered vital elements in the political process. Furthermore, political systems develop habits of response; they routinely employ or tend to employ the same instruments to solve what appear to be special problems of the time; such habits only change when there are really catastrophic changes occurring (e.g. a great depression). Hence really fundamental changes of attitude will occur very rarely; as long as they do not occur it will be sufficient to endogenize certain decision rules used by the political leadership. It is not unlikely, however, that we are approaching a period in which these customary decision rules will show themselves to have less and less effect; nevertheless, they will most likely be retained until something really drastic occurs.*

POLICY-TARGET DYNAMICS IN A GLOBAL-MODEL CONTEXT

Dennis Snower
Department of Economics, Institute for Advanced Studies, Stumpergasse 56, 1060 Vienna (Austria) and Department of Economics, Birkbeck College, University of London, 7/15 Gresse Street, London W1P 1PA (UK)

1 INTRODUCTORY REMARKS

Many long-term global models have indicated the need for steering the world economic, environmental, agricultural, and demographic systems towards a global steady state in which, at the bare minimum, the world population's basic material requirements are satisfied. These requirements are usually defined in terms of the stocks of natural resources, capital goods, land, and pollutants as well as the flows of food, energy, and nonfood consumption goods. The need to achieve a global steady state is commonly suggested by the juxtaposition of descriptive and prescriptive global modeling efforts. The descriptive models attempt to picture how the world systems will evolve through time if present-day economic, environmental, agricultural, and demographic policies are pursued. The prescriptive models embody an alternative set of policies which imply a different dynamic development of the world systems.

The juxtaposition of the descriptive and prescriptive modeling outcomes is meant to represent an implicit argument in favor of the policies which the global modelers advocate. Indeed it is frequently self-evident that the world population's basic material requirements are more adequately satisfied under the prescriptive schemes than under their descriptive counterparts. Yet certainly this line of argument is not really compelling. If the models can be accepted as accurate representations of reality and if it can be established that the prescriptive outcomes are more desirable than the descriptive ones then all that follows is that the prescriptive policies are preferable to the current policies. It does not follow that the prescribed policies should be implemented for it has not been shown that these policies are socially optimal (i.e. that these policies are preferable to any other feasible alternatives).

This is a matter of some importance since the major global modelers are far from agreement on the global policies that are to be prescribed. Moreover, the recommended policies of different modelers are frequently in conflict with one another. Yet even if the major modelers were in agreement or if their recommended policies were not mutually exclusive it would still be helpful to know whether these policies are the best we can do, given our imperfect knowledge of the dynamics of world systems. In case of disagreement it would be helpful to have a set of criteria whereby the various policy alternatives could be evaluated.

This paper is an attempt to clarify why such criteria are necessary in global modeling and how they can be constructed. From a brief discussion of the major global models (which follows later) it emerges that global modelers have not, as yet, been concerned with the social-optimality properties of their policy recommendations. This paper gives an account of analytical prerequisites which a global model should satisfy in order for the social value of different policies to be coherently assessed. Insofar as global models deal with the satisfaction of human material needs one prerequisite is that specific policy targets with regard to resource depletion, pollution, population growth, capital accumulation, land use, etc., should be formulated and that policy recommendations should be described in terms of the temporal evolution of these targets. By means of a simple illustrative global model we show how socially optimal target paths may be chosen.

2 AN OVERVIEW AND ASSESSMENT

A glance at the major global models reveals that global modelers do not justify their policy recommendations by showing that they are preferable to all feasible policy alternatives. Instead, as we have noted already, they rely on a comparison between the forecasts of their descriptive models and the simulations of their prescriptive ones. Most of the descriptive global models predict an eventual leveling-off in economic activity and population. For some models, such as that of Kahn et al. (1976), this leveling-off occurs once many of the basic human needs with regard to food, energy, natural resources, and environmental quality have been met (although pockets of poverty, particularly in the Indian subcontinent, may persist for a long time).

Yet for the predominant majority of descriptive models the leveling-off is a socially undesirable phenomenon. In the studies of Forrester (1971) and Meadows et al. (1972) it comes in the form of "overshoot and collapse". Largely on account of lags in population and pollution dynamics the growth of economic activity and the deterioration of the environment do not come to an end once the earth's environmental, agricultural, and resource carrying capacity has been reached. Consequently catastrophes initiated by resource shortages, pollution, and land shortages and manifested in dramatic increases in death rates are predicted.

Whereas the models of Forrester and Meadows et al. suggest that the breakdown of economic activity and population is likely to occur within the next 100 years, the Ehrlichs argue that the collapse is already under way: the earth is already overpopulated and ecological damage has already been done (Erlich and Erlich, 1970; Erlich, 1971; Erlich and Harriman, 1971). Instead of making detailed predictions of how this situation will evolve in the future they describe a number of instances in which our planet is failing to cope with industrialization, population, and pollution. Under present policy schemes they expect these instances to multiply in the future.

According to Heilbronner (1974), the end of economic growth is presaged by "the descent of large portions of the underdeveloped world into a condition of steadily worsening social disorder, marked by shorter life expectancies, further stunting of physical and mental capacities, political apathy intermingled with riots and pillaging when crops fail" (Heilbronner, 1974, p. 24). The widening gap between rich and poor countries increases the likelihood of war (which represents a possible alternative to thermal collapse).

This gap is also the concern of Mesarovic and Pestel (1974), although these authors do not match Heilbronner's relentless fatalism. They point to the possibility of a sequence of regional collapses, beginning in the region they denote as South and Southeast Asia and spreading via the resource, food, and energy supplies which different countries share with one another.

Naturally the predictions of these and other descriptive global models are contingent on the continuation of current economic, environmental, agricultural, and demographic policies. The prescriptive models, in contrast, are driven by different policies which are designed to yield more favorable global steady states. The work of Kahn et al. (1976) is an exception to this rule since these authors consider the dynamic evolution of their descriptive model to be socially acceptable. Yet, for the most part, the policies that are prescribed by global modelers are quite at variance with those that are implemented nowadays.

Forrester (1971) and Meadows et al. (1972) each provide an ambitious shopping list of conditions whereby a global collapse may be avoided and a steady state may be attained in which (on average) the world population's basic material requirements are fulfilled. For example, the list of Meadows et al. includes a constant overall level of the capital stock, a one-shot increase in the average lifetime of capital equipment, a constant world population, a constant flow of food, a reduction in the use of natural resources per unit of output to one-quarter of the 1970 level, a reduction in the flow of pollutants per unit of output to one-quarter of the 1970 level, and a one-shot rise of agricultural capital relative to industrial capital (Meadows et al., 1972, pp. 163, 164). There is no discussion of whether these goals are attainable or, more fundamentally, whether these goals are preferable to other conceivable goals which also avoid collapse and lead to an acceptable steady state.

The desiderata of the Erlichs (Erlich and Erlich, 1970; Erlich, 1971; Erlich and Harriman, 1971) are not specified with such precision but there is a general call for "de-development" of industrialized countries, a dramatic redistribution of wealth from rich to poor countries (involving a transfer of 20% of the rich countries' national product over a period of 15 years), the "semidevelopment" of most underdeveloped countries and the abandonment of the rest, and the rapid adoption of a conservationist ethic (with the help of religious, educational, and legal institutions). Heilbronner (1974), for his part, points to the need for authoritarian regimes to cope with the economic, environmental, and political problems which he foresees. He also calls for a short-term redistribution of wealth and the adoption of relatively nonpolluting technologies. The Ehrlichs and Heilbronner do not spell out the precise effects that their recommended policies may be expected to have on food levels per capita, the stock of natural resources and pollutants, the production of energy, etc. They simply leave the impression that a more desirable state of the world could be achieved through their suggestions than through current policies.

Mesarovic and Pestel (1974) argue that "organic growth" of the world system is necessary to avoid the regional collapses which they deem possible (Mesarovic and Pestel, 1974, p. 196). This implies a worldwide synchronization of countries' growth rates and a coordination of their trade requirements. The global input–output study of Leontief et al.

(1976) is also concerned with such synchronization, as part of a scheme to reduce the income gap between rich and poor countries. It is shown how this goal may be served through a rapid expansion of world trade and increased investment in poor countries.

The degree of desirable interdependence between rich and poor countries has been a subject of controversy in global modeling. At one end of the spectrum are the studies of Kaya and Suzuki (1974) which call for a comprehensive international division of labor. At the other end lies the work of Herrera et al. (1976) which proposes that the basic material needs of people in given well-defined regions should be satisfied exclusively through the local resources of those regions. Tinbergen's study (Tinbergen, 1976), which not only emphasizes the desirability of poor countries becoming more self-reliant (particularly in the exploration and processing of their natural resources) but also articulates the need to develop industries in accordance with the principle of comparative advantage, probably occupies the middle ground in this controversy. It is difficult to evaluate the merits of these various global models and the associated policy recommendations for nowhere are these recommendations justified in relation to their competing alternatives.

Some of the prescriptive global models referred to are represented in mathematical terms while the others are described verbally. The models differ considerably from one another in terms of the representation of the world population's material requirements, the specified interrelations among the world's economic, environmental, agricultural, and demographic systems, and the degree of geographic and industrial aggregation. However, what all these prescriptive models appear to have in common is that they describe the transition to a global steady state resulting from a given set of recommended policies.

It is safe to say that most of the global models are capable of achieving more than one global steady state. The recommended steady state is simply one of many possibilities and global modelers characteristically do not justify their choice of a particular steady state over all other candidates. Furthermore, the transitional path leading to the global steady state is usually not unique either. Here, also, global modelers have failed to show why their recommended transitional paths are preferable to the other feasible alternatives.

For several global models such as those of Forrester (1971) and Meadows et al. (1972) the transitional path merely rests on a set of technological, sociological, and demographic prerequisites which may or may not be achievable. The practical means whereby these prerequisites can be met is simply not given consideration. In the words of Meadows et al., "We can say very little at this point about the practical, day-by-day steps that might be taken to reach a desirable, sustainable state of global equilibrium. Neither the world model nor our own thoughts have been developed in sufficient detail to understand all the implications of the transition from growth to equilibrium" (Meadows et al., 1972, p. 180).

Other global models describe the practical means whereby an acceptable steady state may be approached – Spengler's taxes on population (Spengler, 1966), Heilbronner's authoritarian regimes (Heilbronner, 1974), Schumacher's reductions in the scale of technologies and organizations (Schumacher, 1973), the Ehrlichs' "de-development" of industrialized countries (Erlich and Erlich, 1970) – without a concrete description of how these practical means would be used to satisfy human needs. All too often global modelers advocate the use of new policy instruments and social institutions without clarifying what these innovations would imply for the production of food, energy, and capital goods and for resource depletion, pollution generation, and population growth.

What these models are missing is a specification of socially desirable policy targets for these variables.

Presumably, prescriptive global models would have a bigger impact on actual policy making than they now enjoy if they would offer concrete descriptions of the policy targets underlying their dynamic paths and if they would investigate the feasibility and social optimality of these policy targets. Only when a given set of policy targets has been shown to be achievable and socially preferable to the other sets of achievable policy targets has a strong argument been made. The sweeping reforms propounded by many global modelers are unlikely to gain practical acceptance in the absence of such an argument.

This paper is concerned with the portrayal of policy targets which set a global model on a socially optimal transition path to a socially optimal steady state. The methodology of finding these targets can be described succinctly with reference to a very simple global model. Of the many ingredients in the satisfaction of those human needs that are commonly treated by global models, our model will be concerned with only two: food production and pollution. A framework for the empirical study of these two ingredients and their interdependence has been provided by Cumberland (1966), Daly (1968), Leontief (1970), and others. Our model is constructed at a much higher level of aggregation than these and has a somewhat more general theoretical structure (e.g. it is not based on fixed-coefficient production functions). Although it would not be difficult to include ingredients other than food production and pollution in our analysis, the main principles underlying the derivation of the optimal policy targets can be uncovered quite simply with reference to these two.

In our model the criteria for the choice of an optimal global steady state and the choice of an optimal transition path to this steady state emerge as a straightforward application of optimal control theory (much in the spirit of D'Arge and Kogiku (1973), Forster (1973), Keeler et al. (1972), Mäler (1974), Plourde (1972), and Smith (1972)). It will be shown how the optimal global steady state depends on technological relations and social preferences. We will describe the policy targets which lead to this steady state along an optimal transition path from a conjectural current state. Our analysis suggests that the derivation of these targets calls for more than casual attention, for their dynamic properties may seem paradoxical at first sight.

In particular, the optimal target paths for our model are not monotonic through time. Assuming that the current state of the world system is characterized by a pollutant stock which is rising and greater than the optimal steady-state stock, we find that the optimal food-production target and the optimal anthropogenic pollution-treatment target both reverse their direction of movement through time. By contrast, the global models in vogue today do not recommend such intertemporal reversals. Under the foregoing assumption these models would characteristically prescribe monotonic target movements through time (e.g. an asymptotically vanishing rise in anthropogenic pollution treatment).

Our conclusion regarding the intertemporal reversals of the food-production target and the anthropogenic pollution-treatment target should not suggest that this "behavior mode" (to use the terminology of Meadows et al., 1972) must invariably be observed in real-world policy making. A broadening of the scope of our analysis to include capital accumulation, resource depletion, and population dynamics may imply the social optimality of a different behavior mode. Our conclusion simply suggests that the optimality of monotonic target movements cannot be taken for granted. Current global models have perhaps treated policy-target dynamics in too cavalier a fashion.

A possible objection to the control-theoretic treatment of global models may be the computational difficulty of such an undertaking. Several global models contain a large number of variables and equations and for these the computation of optimal state and control trajectories may be an unmanageable task. Yet this circumstance does not necessarily imply that these models escape the need to justify their prescriptions in terms of competing alternatives. In many cases it may be possible to simplify and aggregate the relations of a global model – i.e. to build "a model of a model", much as Nordhaus (1973) did with respect to Forrester's model (Forrester, 1971) – and the small-scale version may then be subjected to optimal control analysis. Surely such an indirect defense of global policy prescriptions is better than no defense at all.

In the next section a simple descriptive global model of food production and pollution is constructed. Then, in the final section, we deal with the prescriptive counterpart of this model and investigate the social optimality of the associated policy targets.

3 A SIMPLE DESCRIPTIVE MODEL

As noted earlier, our model restricts itself to the interrelated problems of food production and pollution. The many other sources of human material well-being which are commonly examined by global models (capital accumulation, resource depletion, population growth, etc.) are not considered here. Accordingly only three outputs are generated by our world economy: food, pollutants, and pollution-treatment services. The world population and labor force are assumed to be constant; all other factors of production (natural resources, capital equipment, land, etc.) are held constant as well.

Both food and the pollution-treatment service are assumed to be nondurable. The flow of food F satisfies a consumption demand. The flow of treatment services T reduces the stock of pollutants. The available factors of production are used to produce these two outputs. The technological relation between these outputs may be described by a production-possibility frontier:

$$T = T(F) \qquad T' < 0, \quad T'' < 0 \tag{1}$$

The production and consumption of F as well as the production of T generate a flow of pollutant emissions:

$$\dot{P}_{\mathrm{E}} = g(F, T) \qquad g_F, g_T > 0; \quad g_{FF}, g_{TT} > 0; \quad g_{FT} = 0 \tag{2}$$

The pollutant may be cleansed (i.e. transformed into harmless substances) by the anthropogenic-treatment service (T) and by natural-treatment processes (T_{N}) such as biodecomposition. The magnitude of the latter treatment process is assumed to depend on the existing pollutant stock:

$$T_{\mathrm{N}} = h(P) \qquad h' > 0, \quad h'' < 0 \tag{3}$$

where P is the pollutant stock. Both treatment services are calibrated in such a way that one unit of treatment service corresponds to one unit of pollutant flow cleansed. The net pollutant flow generated by the economy is

$$\dot{P} = \dot{P}_{\mathrm{E}} - T - T_{\mathrm{N}} \tag{4}$$

Substituting eqns. (1)–(3) into eqn. (4), we obtain

$$\dot{P} = k(F, P) \qquad k_F > 0,\ k_P < 0;\ \ k_{FF} > 0,\ k_{PP} > 0;\ \ k_{FP} = 0 \tag{5}$$

We call this technological relation the "production–pollution transformation function".

The descriptive model may be completed by including a forecast of food production under current economic policies (e.g. current agricultural subsidies). For simplicity let the predicted food flow be constant through time:

$$F = \bar{F} \tag{6}$$

The predicted pollutant flow may then be described by the phase diagram of Figure 1. Point A is the global stationary state which the model predicts will be approached under current policies. This stationary state may be socially undesirable; for example, it may be characterized by a level of pollution which is incompatible with human life.

A different dynamic path for food production would imply a different dynamic path for the pollutant flow. Global modeling efforts commonly center around the task of finding dynamic paths for F and $\dot{P}$ which are *preferable* to the paths generated by current policies. By contrast, we now inquire how the socially *optimal* paths for F and $\dot{P}$ may be identified.

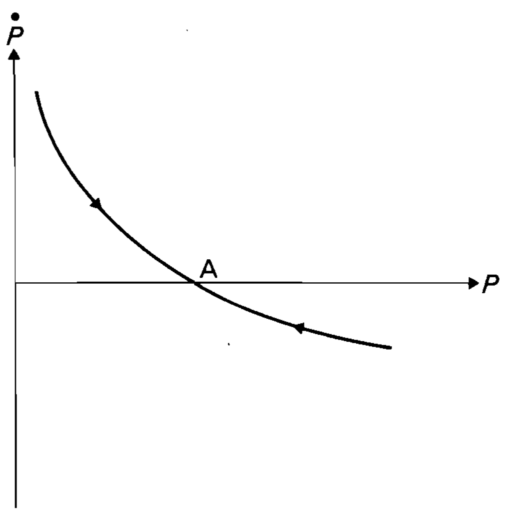


FIGURE 1 A phase diagram describing the predicted pollution flow.

4 OPTIMAL POLICY-TARGET DYNAMICS

As a first step toward finding the optimal time paths of food production and the pollutant flow we describe a conjectural state of the world system (in terms of $F, \dot{P}$, and P). Our description is based on two hypotheses: (i) given the current levels of anthropogenic and natural-treatment services and given the current levels of food production and consumption, the pollutant stock is rising through time; (ii) the current stock of pollutants is greater than its long-run socially optimal stationary-state value. Presumably, most environmental economists would concur with these hypotheses (although the realism of the first is impossible to establish at our level of aggregation and the second is a matter of value judgement).

Figure 2 depicts the production–pollution transformation function in terms of the food flow and the pollutant stock. The $\dot{P} = 0$ function is upward sloping since $-(k_P/k_F)$ is positive. To the left of the $\dot{P} = 0$ function the production of food is sufficiently high and the anthropogenic and natural treatment services are sufficiently low for the pollutant stock to rise. To the right of the $\dot{P} = 0$ function the pollutant stock falls. The long-run socially optimal pollutant stock (which we have yet to derive analytically) is denoted by P^*.

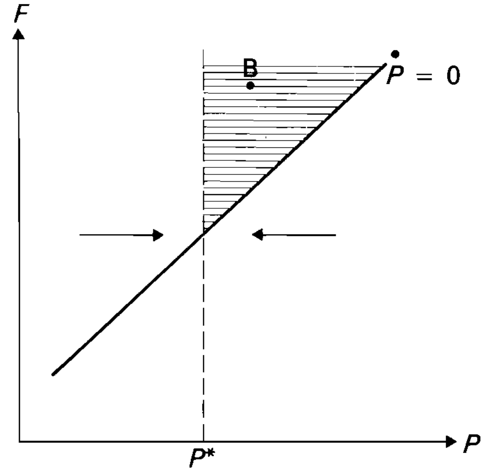


FIGURE 2 The production–pollution transformation function in terms of the food flow F and the pollutant stock P.

Our first hypothesis implies that the conjectural current state of the world system lies to the left of the $\dot{P} = 0$ function. Our second hypothesis implies that this state lies to the right of the P^* line. Hence the conjectural current state is to be found somewhere within the shaded area of Figure 2, say at point B.

In order to evaluate the social desirability of food flows and pollutant flows it is convenient to postulate a social-welfare function. Social welfare at any instant of time is taken to depend positively on the flow of food and inversely on the stock of pollutants:

$$U = U(F,P) \qquad U_F > 0,\ U_P < 0;\quad U_{FF} < 0,\ U_{PP} < 0;\quad U_{FP} = 0 \tag{7}$$

The welfare effects of pollution are long lived. The present production and consumption of food generate pollutants which adversely affect welfare in the future. Thus the problem of finding the socially optimal policy targets for food flows and anthropogenic-treatment services is an intertemporal one. Let the social welfare functional for the evaluation of the target paths be

$$W = \int_0^\infty e^{-rt}\, U(F,P)\, dt \tag{8}$$

where r is the social rate of time preference.

The optimal target paths may be identified by maximizing this function subject to the production–pollution transformation function:

$$\text{Maximize } W = \int_0^\infty e^{-rt}\, U(F,P)\, dt \qquad \text{subject to } \dot{P} = k(F,P) \tag{9}$$

where F is the control variable and P is the state variable.

The first-order conditions for social optimality imply the following differential equations for food production and the pollution flow respectively:

$$\dot{F} = [F/(\sigma^U_{FF} - \sigma^k_{FF})]\,[(U_P/U_F)k_F + (r - k_P)] \tag{10}$$

$$\dot{P} = k(F,P) \tag{5}$$

where

$$\sigma^U_{FF} = (U_{FF}/U_F)F < 0$$

(the elasticity of marginal utility from food consumption with respect to food consumption) and

$$\sigma^k_{FF} = (k_{FF}/k_F)F > 0$$

(the elasticity of marginal net pollutant flow from F with respect to F) are both assumed to be constants.

Figure 3 illustrates the trajectories satisfying the first-order conditions. Of all these trajectories, the only ones which also satisfy the sufficient conditions for social optimality lie on the two branches of the saddle-point path, denoted by the broken line *SPP* in Figure 3. It can be shown that the saddle-point path must be downward sloping. The socially optimal stationary state is described by the point (P^*, F^*), which lies at the intersection of the $\dot{F} = 0$ and $\dot{P} = 0$ functions.

The optimal transitional trajectory leading from the conjectural current state to the optimal stationary state is pictured in Figure 4. This trajectory may be characterized in terms of its underlying food-production target and anthropogenic-treatment target. The movements of the two targets may be divided into short-run, medium-run, and long-run

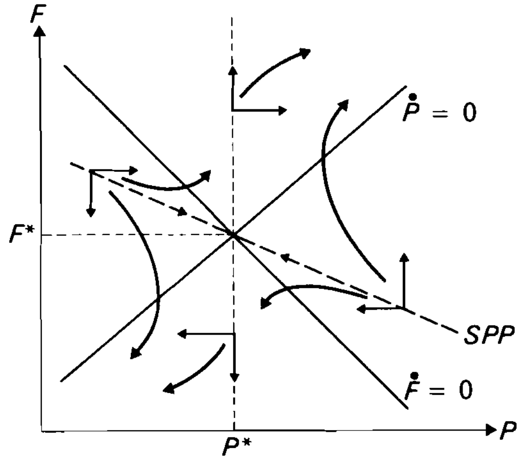


FIGURE 3 The trajectories which satisfy the first-order conditions for social optimality.

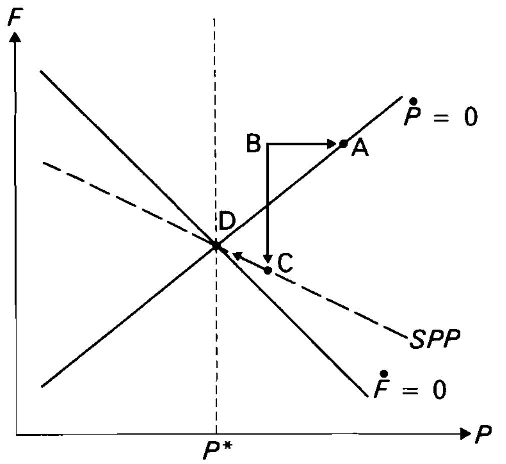


FIGURE 4 The optimal trajectory (BCD) leading from the conjectural current state to the optimal stationary state and the forecast trajectory (BA) of the descriptive model.

components. The short run is sufficiently short for the pollutant stock to remain at its historically given initial value. The medium run is sufficiently long to permit changes in the level of the pollutant stock but not long enough for the optimal stationary state to be reached. In the long run the complete adjustment from the conjectural current state to the optimal stationary state takes place.

With regard to this temporal classification scheme it is evident that the world system must move from point B to point C in the short run. Thus there must be a short-run fall in the food-production target and a short-run rise in the anthropogenic-treatment target.

(A fall in the latter target is required because the pollutant stock and, with it, the natural-treatment service remain unchanged in the short run and because the pollutant stock is increasing at point B and decreasing at point C.) In the medium run a movement from point C to point D must be induced. Consequently the food-production target must rise while the anthropogenic-treatment target must fall. (The rise in the food-production target necessitates a transfer of factors into food production from pollution treatment.) In the long run the entire transition from point B to point D is completed; point D is characterized by a lower food flow and a lower pollutant stock than point B.

In sum, the socially optimal dynamic paths of the food-production target and the anthropogenic-treatment target are implicit in the trajectory BCD in Figure 4. This trajectory differs from the forecast trajectory of the descriptive global model (BA in Figure 4 (where point A in Figure 4 corresponds to point A in Figure 1)). It is noteworthy that both targets reverse their direction of movement along their optimal paths: the food production target falls in the short run and rises in the medium run while the anthropogenic-treatment target rises in the short run and falls in the medium run.

The desirability of such intertemporal reversals has not been investigated by global models so far. Naturally the fact that these reversals are optimal in our simple model does not mean that they must also be optimal in a more complex analytical setting but certainly this matter deserves some serious attention. It cannot be taken for granted that the monotonic target paths, which are so common in prescriptive global models, are necessarily the best paths to be followed.

The second hypothesis underlying our description of the conjectural current state implies that the stock of pollutants should be reduced in the long run. It is possible to achieve this reduction through monotonic changes of the targets. Figure 5 illustrates the trajectory that would be induced by such a policy. Throughout the trajectory there is a steady fall of the food-production target and a steady rise of the anthropogenic-treatment target. In the initial phase of this trajectory the production of food is sufficiently high and the treatment of pollution is sufficiently low that the pollutant stock rises. Yet as resources are transferred out of food production and into anthropogenic pollution treatment, the pollutant stock rises at a slower and slower rate and eventually falls toward P^*.

This trajectory may be socially more desirable than the forecast trajectory BA but it is not optimal. The argument that trajectory BD is preferable to trajectory BA is not a foolproof defense of the policies underlying BD. For our model it has been shown that the optimal trajectory implies intertemporal reversals of both targets and trajectory BD does not meet this prerequisite.

This does not mean that a global modeler who advocates the policies underlying trajectory BCD (of Figure 4) necessarily has a compelling case. His policy recommendations depend, in part, on his choice of social-welfare function and in this area there is room for disagreement among equally informed and farsighted people. For example, another global modeler may be more "pollution conscious" or less "consumption conscious"; in particular, this second modeler may favor a social-welfare function with a higher marginal utility U_F of food or a lower marginal disutility $-U_P$ of pollution. In Figure 6 the optimal trajectories associated with the two differing social preferences are compared. The $\dot{F} = 0$ function of the second modeler lies beneath that of the first modeler. (The reason is that with reference to eqn. (10), $\partial\dot{F}/\partial U_F$ and $\partial\dot{F}/\partial U_P$ are both negative while $\partial\dot{F}/\partial F$ is positive.) Consequently the second modeler's saddle-point path

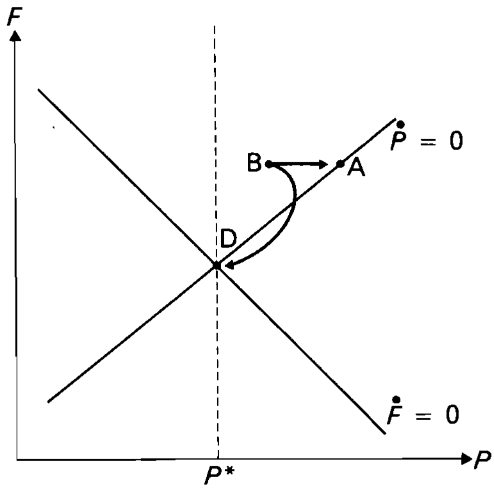


FIGURE 5 The trajectory (BD) induced through monotonic changes in the targets to reduce the pollutant stock in the long run and the forecast trajectory (BA) of the descriptive model.

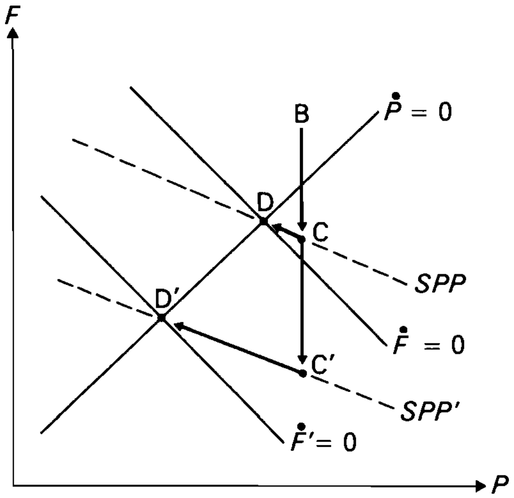


FIGURE 6 The optimal trajectories (BCD and BC′D′) for two modelers with different social preferences. The second modeler (trajectory BC′D′) uses a social-welfare function with a higher marginal utility U_F of food or a lower marginal disutility $-U_P$ of pollution than does the first modeler (trajectory BCD) (see text).

lies beneath that of the first modeler. Thus the second modeler recommends a larger short-run fall of the food-production target, a larger short-run rise of the anthropogenic-treatment target, and a larger long-run fall of the pollutant stock.

This type of disagreement over policy formulation is certainly conceivable. In a similar vein, global modelers may have different conceptions of technological relations in the future and these differences may also lead to divergent policy recommendations. Such policy disagreements may be difficult to resolve but it is certainly useful to trace them back to differences in social preferences and in technological assumptions. This identification of fundamental reasons for policy disagreement is not possible under present global modeling practice, whereby policy recommendations are defended by merely showing that they are preferable to current (or predicted) policies. Certainly, many mutually exclusive sets of policies may be improvements over the current ones but demonstrations to that effect do not indicate which of these sets of policies should be implemented. Only when such demonstrations have been abandoned in favor of investigations into the social optimality of recommended policies is there hope of deciphering the basic reasons for policy disagreements.

REFERENCES

Cumberland, J. (1966). A regional interindustry model for analysis of development objectives. Regional Science Association Papers, 17: 65–95.

Daly, H.E. (1968). On economics as a life science. Journal of Political Economy, 76: 392–406.

D'Arge, R. and Kogiku, K. (1973). Economic growth and the environment. Review of Economic Studies, 40: 61–77.

Ehrlich, A. and Ehrlich, P. (1970). Population, Resources, Environment – Issues in Human Ecology. Freeman, San Francisco, California.

Ehrlich, P. (1971). The Population Bomb. Pan Books, London.

Ehrlich, P. and Harriman, R. (1971). How to be a Survivor. Pan Books, London.

Forrester, J.W. (1971). World Dynamics. Wright-Allen, Cambridge, Massachusetts.

Forster, B. (1973). Optimal consumption planning in a polluted environment. Economic Record, 49: 534–545.

Heilbronner, R.L. (1974). An Inquiry into the Human Prospect. Norton, New York.

Herrera, A., et al. (1976). Catastrophe or New Society? International Development Research Center, Ottawa, Canada.

Kahn, H., Brown, W., and Martel, L. (1976). The Next 200 Years. Morrow, New York.

Kaya, Y. and Suzuki, Y. (1974). Global constraints and a new vision for development. Technological Forecasting and Social Change, 6.

Keeler, E., Spence, M., and Zeckhauser, R. (1972). The optimal control of pollution. Journal of Political Economy, 4: 19–34.

Leontief, W. (1970). Environmental repercussions and the economic structure: an input–output approach. Review of Economics and Statistics, 2: 262–271.

Leontief, W., et al. (1977). The Future of the World Economy. Oxford University Press, New York.

Mäler, K. (1974). Environmental Economics. Johns Hopkins University Press, Baltimore, Maryland.

Meadows, D.H., Meadows, D.L., Randers, J., and Behrens, W.W., III (1972). The Limits to Growth. Universe Books, New York.

Mesarovic, M. and Pestel, E. (1974). Mankind at the Turning Point. Dutton, Readers Digest Press, New York.

Nordhaus, W.D. (1973). World dynamics: measurement without data. Economic Journal, 83: 1156–1183.

Plourde, C.G. (1972). A model of waste accumulation and disposal. Canadian Journal of Economics, 5:119–125.

Schumacher, E.F. (1973). Small is Beautiful – A Study of Economics as if People Mattered. Blond and Briggs, London.

Smith, V.L. (1972). Dynamics of waste accumulation: disposal versus recycling. Quarterly Journal of Economics, 86: 600–616.

Spengler, J. (1966). The economist and the population question. American Economic Review, 56: 1–24.
Tinbergen, J. (1976). Reshaping the International Order. Dutton, New York.

DISCUSSION

Muller *asked* Snower *whether the occurrence of intertemporal target reversals depended on the smooth and continuous functional form of the production–pollution transformation function (eqn. (5)).* Muller *hypothesized that the relation between the pollutant stock and the level of natural pollution-treatment activity may be neither smooth nor continuous. As an extreme case he imagined the following relation. (a) At relatively low levels of pollutant stock nature assimilates most of the pollution from the consumption, production, and treatment activities. Thus in* Snower's *model* F *could be increased without significantly affecting* P. *(b) However, beyond a certain threshold level* P^0 *of the pollutant stock natural assimilation activity stops. In other words, increases in* F *lead to increases in* P, *which in turn, however, exert no damping influence on* $\dot{P}$. Muller *inquired whether such postulated relations would eliminate the need for intertemporal target reversals.*

Snower *replied that amending his model to allow for* Muller's *two hypotheses would not affect the social desirability of intertemporal target reversals. He showed that* Muller's *hypotheses imply a particular functional form of the* $\dot{P} = 0$ *relation (of Figure 1): beneath* P^0 *a segment of the* $\dot{P} = 0$ *function is steeply upward sloping (nearly vertical) and above* P^0 *the* $\dot{P} = 0$ *function is horizontal.* Snower *indicated that, given a negatively sloped* $\dot{F} = 0$ *function, both a horizontal and a vertical* $\dot{P} = 0$ *function imply a negatively sloped saddle-point path* (SPP). *The social desirability of intertemporal target reversals depends on the initial state of the world system (pictured by point* B *in Figure 4) and on the slope of the saddle-point path.* Muller's *hypotheses affect neither of these prerequisites.*

Muller *pointed out that his two hypotheses could be modified in various ways. The production–pollution transformation function may be continuous but not smooth. For example, at a certain threshold level of the pollutant stock, nature's* marginal *assimilation activity* (dT_N/dP) *may fall abruptly from an initial positive value to a lower positive value.*

Snower *showed that this modification implies a kinked upward-sloping* $\dot{P} = 0$ *function. This function in turn implies a negatively sloped saddle-point path and thus the social desirability of intertemporal target reversals remains unaffected.*

Muller *suggested a further modification of the production–pollution transformation function. He supposed that beneath a certain threshold level* P^0 *of the pollutant stock the extent of natural treatment activity varies with the size of the pollutant stock, whereas above* P^0 *nature's treatment becomes counterproductive (i.e. far from assimilating the pollutant stock, nature contributes to it). Would this possibility obviate the need for intertemporal target reversals?*

Snower *indicated that counterproductive natural treatment is far more than a theoretical possibility. The problem of eutrophication (whereby, say, the fishing and recreational uses of a lake are diminished not only through the accumulation of de-*

composable organic wastes but also through the concomitant growth of underwater vegetation) is a serious practical instance of this possibility. Snower *showed that for this case the* $\dot{P} = 0$ *function is upward-sloping for* $P < P^0$ *and downward-sloping for* $P > P^0$. *Consequently there may be more than one stationary state. For example, in Figure D1*

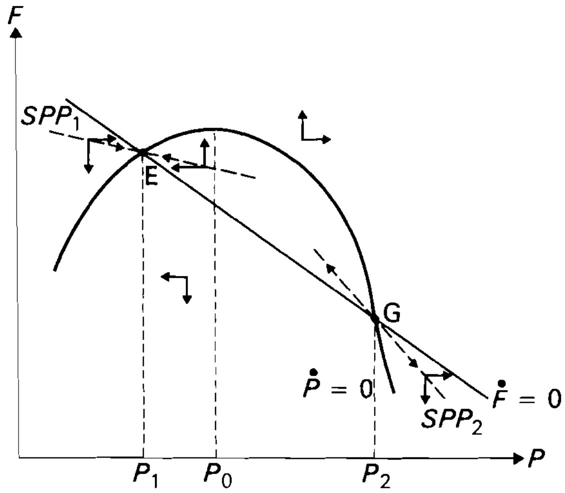


FIGURE D1 The two stationary states E (stable) and G (unstable) and the optimal trajectories for the case of counterproductive natural treatment.

two stationary states are pictured. One of these states is stable (point E) and the other is unstable (point G). For $P < P_2$ *it is socially desirable for the world system to pursue a trajectory which ultimately coincides with* SPP_1. *For* $P = P_2$ *food production should be adjusted in the short run so that point G is attained. For* $P > P_2$ *an optimal trajectory does not exist. Leaving aside the possibility that* $P \geqslant P_2$, *the case for intertemporal target reversals remains unaffected.*

Snower *concluded by explaining that intertemporal target reversals are not invariably optimal. For instance, the introduction of discrete lags into the production–pollution transformation function may give rise to target trajectories which do not reverse their direction of movement through time.* Snower *emphasized that he is not advocating the unquestioned implementation of intertemporal target reversals but is simply indicating that such reversals might be socially desirable. This possibility alone suggests that optimal pollution–food trajectories of the world system may be more complex than many global modelers appear to envisage. Hence the social-optimality criteria underlying global policy recommendations may be well worth investigating.*

Bruckmann *thanked* Snower *for his stimulating thoughts. He agreed that there is insufficient awareness of the possible desirability of environmental-economic policies reversing themselves through time. He maintained that promotion of this awareness makes the struggle through* Snower's *differential equations worthwhile!*

AFTERWORD

Gerhart Bruckmann
International Institute for Applied Systems Analysis, Laxenburg (Austria)

Whenever a conference is over one ought to pause for a moment, sit back, and ponder the question of what the conference has actually achieved. It was Dr. Kuzmin who, at an earlier stage, had said that this conference pretty well reflected the state of affairs in the field of how to incorporate environmental aspects into global models.

This comment can be interpreted either positively or negatively. Negatively in the sense that all of us who had come here, after many frustrating years of struggling in vain, in the hope of finally finding the philosopher's stone will have to return home with this hope still unfulfilled. But the positive aspect of the remark was felt all through this conference: we experienced the fascination of constantly finding ourselves right on the frontiers of today's knowledge. It may be safely stated that nobody working on the interface between ecological modeling and global modeling who has not participated in this conference could have contributed any more than what the presentations and discussions at this conference have brought forth. We know that we are still far from really operational ecological models, and, hence, far from incorporating such models in an easy-to-play-with way into global models. But when, in our future work, we continue to dream the undreamable dream, to model unmodelable relations, we shall, from now on, have a slightly better feeling, a better understanding of the difficulties of the underlying relationships. This conference has definitely added a few more pieces of mosaic to what is still a far from clearcut comprehensive picture.

There is another aspect which may prove to be even more important than having increased our knowledge here and there. It is that this conference has, for the first time, brought together ecologists and global modelers. Until now, global modelers did not really understand the difficulties ecologists have to face, and ecologists often frowned upon global modelers, rightfully accusing them of working from unwarranted assumptions. If this conference has improved mutual understanding, has broken the ice between two disparate bodies of scientists, then this aspect may turn out to be its most valuable achievement.

And it is in this spirit that I wish to thank everybody who contributed so actively to making this conference a success.

CLOSING REMARKS

Roger E. Levien
International Institute for Applied Systems Analysis, Laxenburg (Austria)

In closing, let me say a few words about the way IIASA perceives this series of conferences and its own interest in global problems and large-scale modeling. First, as I noted earlier, there is a high probability that we will have a conference next year on international economic modeling. That will be the eighth in this very successful series. IIASA has about 30 conferences a year and several of them are annual events, but the Global Modeling Conferences have had the most internal dynamism, reflecting the strong interest of the participants in continuing the series. This has encouraged IIASA to support them, even in the face of occasional inclinations to say "well, we have covered the field". Consequently, I anticipate that the series will be carried on as long as the demand for it exists.

Now let me comment about IIASA's engagement with global modeling which I take to be large-scale, multisectoral models of global scope. First, we are studying issues of global scope. At the moment, our focus is on food and agriculture and on energy, but in the coming years, and in fact in the coming months, we are going to have to consider what other global issues we want to take into our agenda. There are several possibilities. One is the relationship between human activities and the global climate. We have already touched this subject in our Energy Program, and it obviously has relevance to our Food and Agriculture Program. A World Climate Program is being initiated under the leadership of the World Meteorological Organization in Geneva and there has been some suggestion that IIASA might contribute to it by examining the relationship between human activity and the climate. So a concern for global climate issues may evolve. That would certainly lead us into certain kinds of modeling; both geophysical modeling, which we would not do ourselves, and economic and other human activity modeling, which we might undertake on a global scale. The second issue is industrial development. A problem common to the developed countries and the developing countries as we face changes in the prices of raw materials (particularly energy), shifts in technology, and shifts in the comparative advantage of different countries, is what industrial strategy should a country pursue? What new industry should it invest in? Take the case of a small developed economy in Europe, such as that of Sweden: as its major industries – shipbuilding, steel, cars – become less competitive in world markets, what new industries should it invest in? This problem faces all countries, as there are shifts in comparative advantage, changes in prices, and new nations enter the world market. I believe that this issue will be an increasingly important one in the coming decades affecting the shape and wellbeing of industries, nations, and the world. IIASA is trying to find the right way to address it. This issue would certainly warrant modeling having global scope.

Now let me turn to IIASA's interest in large-scale multisectoral modeling. We are already using a number of large-scale models. Both the Food and Agriculture Program and the Energy Program have employed large-scale models, but they are of single sectors (energy or food), even though on a global geographic scale. However, our studies of regional development within a country have been concerned with the linkage of multiple sectoral models (agriculture, water, population, etc.) in order to carry out coherent regional development planning. So while these models do not have global scope, they do share a multisectoral character with most of the global models discussed at this series of conferences. Thus, in this respect, IIASA is concerned with issues very similar to those of concern to global modelers. This leads me to the following thought: the real theme of this series of conferences may be large-scale multisectoral modeling and not necessarily global modeling. And one possible way to continue this series would be to turn to some of the problems that underlie all complex multisectoral modeling: issues of validation, of verification, of documentation, and so on. I would be interested in your reactions to this idea.

I am happy to see among the participants at this conference, a number who have been to IIASA before. One of the most important results of the work of the Institute has been the formation of a community of scientists around the world who are linked through IIASA. I hope that those of you who are new to the Institute will join this community and return often in the future. We need your help if we are to contribute to a better understanding of the global issues facing mankind.

AUTHOR INDEX

LIST OF CONFERENCE PARTICIPANTS

External Participants

M. Ayyad
Botany Department
Faculty of Science
Alexandria University
P.O. Box 589
Alexandria, Egypt

P.R. Benyon
Simulation and Systems Analysis Section
Division of Computing Research
Commonwealth Scientific and Industrial Research Organization (CSIRO)
P.O. Box 1800
Canberra, ACT 2601, Australia

G.E. Brandvold
Solar Energy Products
Department 4710
Sandia Laboratories
Albuquerque, New Mexico 87115
USA

S.A. Bremer
International Institute for Comparative Social Research
Science Center Berlin
Steinplatz 2
D-1000 Berlin (West) 12

R. Codoni
Centre for Economic Research
Swiss Federal Institute of Technology – ETH Centre
CH-8092 Zürich, Switzerland

T. Cusack
International Institute for Comparative Social Research
Science Center Berlin
Steinplatz 2
D-1000 Berlin (West) 12

P. Driessen
Centre for World Food Studies
c/o Agricultural University
P.O. Box 37
6700 AA Wageningen, The Netherlands

D.C. Faber
Centre for World Food Studies
Free University
1105 de Boele Laan
Amsterdam, The Netherlands

B. Györffy
Agricultural Research Institute of the Hungarian Academy of Sciences
P.O. Box 19
H-2462 Martonvasar, Hungary

Zs. Harnos
Bureau for Systems Analysis
Victor Hugo u. 18-22
Budapest, Hungary

N.M. Kamrany
Department of Economics
University of Southern California
University Park
Los Angeles, California 90007
USA

Y. Kaya
Department of Electrical Engineering
University of Tokyo
Hongo 7-3-1
Bunkyo-ku, Tokyo 113, Japan

W.W. Kellogg
National Center for Atmosphere Research
– NCAR
P.O. Box 3000
Boulder, Colorado, USA

S. Kuzmin
Employment and Development Dept.
ILO
CH-1211 Geneva 22, Switzerland

J. Aguilar-Martin
National Centre of Scientific Research
(CNRS)
7, Avenue du Colonel Roche
F-31400 Toulouse, France

M. Mesarovic
Case Institute of Technology
Case University
Cleveland, Ohio 44106
USA

K. Moeller
Institute for Applied Systems Research
Medical University
Karl-Wiechert-Allee 9, Haus WG3
D-3000 Hanover, FRG

J.M. Mula
Department of Science and Environment
Lombard House
Canberra, ACT, Australia

F. Muller
Erasmus University
Borg Outlaan 50
Rotterdam, The Netherlands

Y. Nishikawa
International Atomic Energy Agency
Vienna, Austria

D. Norse
Interfutures, OECD
2, rue Andre-Pascal
Paris, France

K. Parker
Department of Science and Environment
Lombard House
Canberra, ACT, Australia

S.A. Pegov
Institute for Systems Studies
29, Ryleyev Street
Moscow, USSR

B. Pollins
International Institute for Comparative
Social Research
Science Center Berlin
Steinplatz 2
D-1000 Berlin (West) 12

L. Quance
Economics, Statistics and Cooperative
Service
US Department of Agriculture
500, 12th Street, N.W.
Washington, D.C. 22050, USA

P.C. Roberts
Systems Analysis Research Unit
Department of the Environment
2, Marsham Street
London SW1P 3EB, United Kingdom

B. Saugy
Centre for Economic Research
Swiss Federal Institute of Technology –
ETH Centre
CH-8092 Zürich, Switzerland

D. Snower
Institute for Advanced Studies
Stumpergasse 56
A-1060 Vienna, Austria

P. Staub
Centre for Economic Research
Swiss Federal Institute of Technology –
ETH Centre
CH-8092 Zürich, Switzerland

W.A. Steger
CONSAD Research Corporation
121 North Highland Avenue
Pittsburgh, Pennsylvania 15206
USA

J. Stuckey
International Institute for Comparative
Social Research
Science Center Berlin
Steinplatz 2
D-1000 Berlin (West) 12

Y. Suzuki
Department of Electrical Engineering
Faculty of Engineering
Osaka University
Yamada-kami, Suita, Japan

A. Sydow
Central Institute for Cybernetics and
Information Processes
Academy of Sciences
DDR-1199 Berlin-Adlershof, GDR

D.J. Szepesi
Meteorological Service of the Hungarian
People's Republic
Kitaibel Pal utca 1
H-1525 Budapest, Hungary

V. Tikhomirov
UNITAR
801 United Nations Plaza
New York, N.Y. 10017, USA

M.D. Ward
International Institute for Comparative
Social Research
Science Center Berlin
Steinplatz 2
D-1000 Berlin (West) 12

F. Wasserman
Society for the Study of Economic and
Social Development
67, rue de Lille
F-75007 Paris, France

E.R. Williams
Division of Policy Analysis
Office of Environment
Department of Energy
1000 Independence Avenue
Washington, D.C. 20585
USA

IIASA Participants

G. Bruckmann
Global Modeling Review

R. Dobrinsky
Human Settlements and Services

G. Golubev
Resources and Environment

J. Hirs
Food and Agriculture

R. Levien
Directorate

W. Oest
Management and Technology

F. Rabar
Food and Agriculture

J.M. Robinson
Management and Technology

O. Vasiliev
Resources and Environment