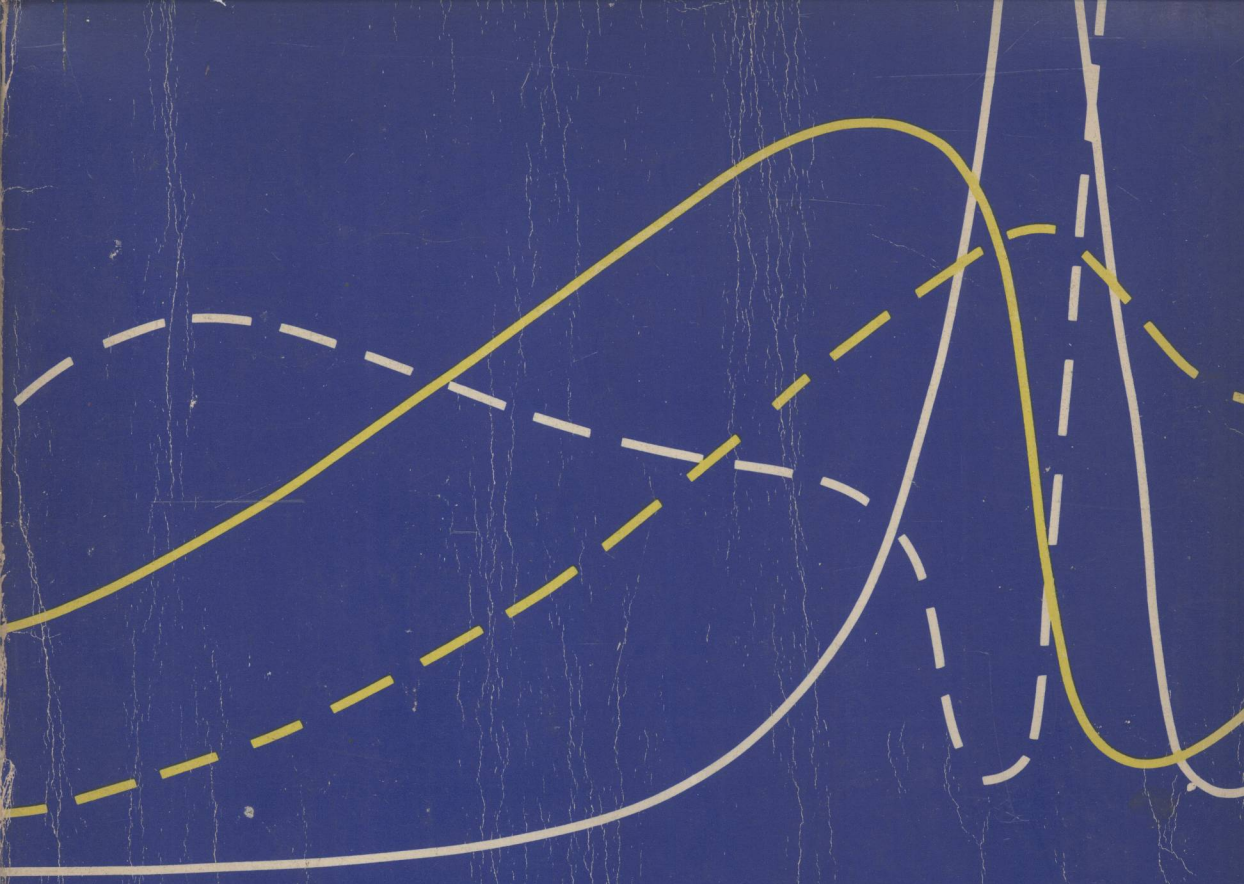

WORLD DYNAMICS

Second edition

Jay W. Forrester

World Dynamics

SECOND EDITION

JAY W. FORRESTER

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World Dynamics

SECOND EDITION

To
Gordon S. Brown

Preface to Second Edition

World Dynamics was first published in June 1971. The successor book, *The Limits to Growth* (Reference 12), became available in March 1972. The two have received an unexpected amount of attention from the public press. Before publication, *World Dynamics* seemed assured of little public notice—the book has 35 pages of equations in the main text, much of the remainder is computer graphical printout, it was distributed by a new and unknown publisher, and it deals not with the present but with issues of several decades hence. The two books, however, have become the center of spirited controversy. Reviews of *World Dynamics* have appeared in such diverse publications as *The Observer* (London), *Fortune, The Wall Street Journal, Science, Playboy, The Christian Science Monitor* and the underground press. The debate over *World Dynamics* and *The Limits to Growth* has become international in extent. The books are now available in several languages.

The responses have tended to be bipolar, some actively supporting and others taking strong exception. Support has come from environmentalists who share the concerns of *World Dynamics.* Many engineers and scientists have found the methodology understandable and based on familiar theory. Contrary to common expectations, many corporate managers, especially senior executives, accept the basic proposition that continued industrialization and population growth will only lead to increased stresses, although the implications for altered present action are not yet clear.

The strongest criticism has come from some economists. The objections range from simple misunderstanding, through belief that essential structures have been omitted from the world model, to concern over the costs and feasibility of halting economic growth. Although there is a basis for the criticisms, they have not had sufficient substance to dismiss the central issues. The debate seems to be gradually moving away from the question of whether or not industrial growth must slow to the question of what strategy should be used to limit growth. The latter question, however, remains unanswered.

A growing inclination to face the problems of growth has appeared among engineers, businessmen, social scientists, and politicians. Seminars, panel discussions, and debates have proliferated on the future of economic growth. But questioning the present trends of economic growth is much easier than finding answers to the questions of when, how, and for whom economic growth should stop.

Before there can be any move away from present policies and practices, alternatives must be identified and explored. The alternatives will involve fundamental changes in laws, values, religious attitudes,* and expectations. Years of debate lie ahead in synthesizing a new political rationale that is compatible with a finite world in which human problems can not much longer be solved by expansion. The challenge is to design a path for both industrial and underdeveloped nations through the transition from growth to a viable equilibrium.

Only by discovering how the ethical, political, physical, technical, economic and social forces of society interact with one another, can we understand the alternative patterns of future development. As space becomes crowded, the different aspects of society have increasing impact on each other. System dynamics has been instrumental in showing how diverse sectors of society interact to create the problems of growth. What can be expected of system dynamics in finding the alternatives to growth?

System dynamics could be the unifying framework and vehicle for interdisciplinary communication. Not only is system dynamics capable of accepting the descriptive knowledge from diverse fields, but it also shows how present policies lead to future consequences. Several years will be required to adequately clarify and argue the nature and merits of future alternatives. Time is short. We must move quickly if we are to keep future options open.

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Cambridge, Massachusetts
May, 1973

*See Forrester, Jay W., "Churches at the Transition Between Growth and World Equilibrium," Chapter 13 in Reference 13.

Preface

Over the last several decades interest in economic development, population growth, and the world environment has expanded rapidly. As world-wide stresses have increased, many individuals and organizations have begun to study and to influence the changing aspects of the world situation. But it seems fair to observe that most of the activity has been addressed to separate facets of the world system. Little has yet been done to show how the many actions and forces are affecting one another to produce the total consequences that we observe. Now however, many persons are coming to believe that the interactions within the whole are more important than the sum of the separate parts. This book was undertaken as one step toward showing how the behavior of the world system results from mutual interplay between its demographic, industrial, and agricultural subsystems.

The present investigation grew from a 15-year program of exploring the dynamic structures of social systems and from a sequence of events in the summer of 1970 that focused the earlier background on the rapidly growing stresses within our largest social system—the world community. Beginning in 1957 with support of a grant from the Ford Foundation, the methods of "industrial dynamics" were developed as a way to understand and to design corporate policy. From that work has developed a general viewpoint about the feedback-loop structure of systems and their subsequent dynamic behavior. The resulting principles and practices have been finding ever broadening applications.

In 1968 along with John F. Collins and others, I extended the approach to the growth and stagnation characteristics of urban areas as described in my book *Urban Dynamics.* A timely grant from the Independence Foundation in Philadelphia supported formation of a group of staff and graduate students to penetrate more deeply into urban behavior. The existence of that group gave us the capability to respond to the events in the summer of 1970 that led to the present book and the continuing project on global dynamics.

On June 29, 1970, I attended a meeting of The Club of Rome in Bern, Switzerland. The Club of Rome is a private group numbering some 75 members

from many countries who have joined together to find ways to understand better the changes now occurring in the world. The members act as private citizens. They are not in governmental decision-making positions. Their orientation is activist—that is, they wish to do more than study and understand. They wish to clarify the course of human events in a way that can be transmitted to governments and peoples to influence the trends of rising population, increasing pollution, greater crowding, and growing social strife.

At the time of the Bern meeting, The Club of Rome had already planned a project on "The Predicament of Mankind." Preliminary goals, a survey of methodologies, and a statement of the "problematique" had been prepared by Aurelio Peccei, Eduard Pestel, Alexander King, Hasan Ozbekhan, Hugo Thiemann, and others. The objective of the project is to understand the options available to mankind as societies enter the transition from growth to equilibrium. Man throughout history has focused on growth—growth in population, standard of living, and geographical boundaries. But in the fixed space of the world, growth must in time give way to equilibrium. Little is known about the social and economic forces that will accompany the entry into world equilibrium.

The June meeting was held to review the status of the project, which was about to begin. Discussion in the meeting revealed that a suitable methodology had not yet been identified to deal with the broad sweep of human affairs and the ways in which major elements of the world ecology interact with each other. Because the "system dynamics" approach as already developed at the Massachusetts Institute of Technology seemed well suited, the group was invited to Cambridge to determine firsthand if they agreed that the methods then existing would be suitable for the next step in the project. As a result, a meeting convened on July 20 for ten days of study, presentations, and discussion.

The dynamic model of world interactions described in this book was devised in the early part of July to form a basis for discussion at the conference. It must be considered a preliminary effort. But all models will be tentative, for new insights will continue to appear. Because a truly final model of the world system is unlikely ever to be achieved, and because of the widespread interest that has already been expressed in this effort, it seems appropriate to present the existing assumptions and implications in this book.

As a result of the July meeting, the Executive Committee of The Club of Rome decided to establish a one-year research program at M.I.T. An international team under the leadership of Professor Dennis L. Meadows is going beyond the model described here to explore more deeply the underlying assumptions and the several major subsystems that form the sectors of the total world system. Substantial extensions are being made into the dynamics of population, pollution, capital investment, and agriculture. The emerging results promise to extend greatly the understanding of world behavior. As of this writing, the new insights do not alter in any substantial way the broad implications reported here.

The continuing project, as well as the July conference, has been made possible by financial support to The Club of Rome from the Volkswagen Foundation (Stiftung Volkswagenwerk) in Germany.

Only broad aspects of the world system are discussed here, not the difficulties of implementing the changes that will be necessary if the present course of human events is to be altered. Many important variables are omitted. Aggregation is at such a high level that the distinctions between developed and underdeveloped countries do not appear explicitly. Most of the concepts in the world model reflect the attitudes and motivations of the recent past and present. Therefore the book does not incorporate the possible changes in human aspirations and values that might come from widespread recognition of the predicament facing mankind. All these and others are issues for future investigation. I hope this book contributes to the sense of urgency and also that it points to an effective direction for work by others who may choose to explore the alternatives for the future.

In spite of the tentative nature of the world model described here, various conclusions are drawn from it. Man acts at all times on the models he has available. Mental images are models. We are now using those mental models as a basis for action. Anyone who proposes a policy, law, or course of action is doing so on the basis of the model in which he, at that time, has the greatest confidence. Having defined with care the model contained herein, and having examined its dynamic behavior and implications, I have greater confidence in this world system model than in others that I now have available. Therefore, this is the model I should use for recommending actions. Those others who find this model more persuasive than the one they are now using presumably will wish to employ it until a better model becomes available.

It is to be hoped that those who believe they already have some different model that is more valid will present it in the same explicit detail, so that its assumptions and consequences can be examined and compared. To reject this model because of its shortcomings without offering concrete and tangible alternatives would be equivalent to asking that time be stopped. But the world will continue to turn. We always use the most acceptable model at any point in time. But how should we proceed so that the most acceptable model is also the best one that is available? We should try for three things. First, the best *existing* model should be identified at each point in time. Second, the best currently existing model should be used in preference to traditional models that may be less clear and less correct. Third, aggressive effort should be devoted to a continual improvement in the available models of the world system.

It seems traditional for explicit models of social systems to be greeted by vague criticisms about their lack of perfection. Instead, we need equally explicit alternatives with a demonstration that the alternative leads to a *different* and *more plausible* set of conclusions. By proposal and counter proposition our understanding of social systems can advance.

I am especially indebted to Gordon S. Brown, John F. Collins, Aurelio Peccei, and Eduard Pestel for encouragement and assistance in the many stages leading to

this book. I also appreciate the helpful criticism of the manuscript from Richard Brown, Robert G. Erwin, John Henize, Dennis L. Meadows, John A. Seeger, and Carroll L. Wilson. Neither they nor The Club of Rome should be held responsible for the assumptions and interpretations presented here.

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March, 1971.

Contents

1 Introduction

1.1 A World System

The world system is encountering new pressures. By "world system" we mean man, his social systems, his technology, and the natural environment. These interact to produce growth, change, and stress. It is not new to have great forces generated from within the socio-technical-natural system. But only recently has mankind become aware of rising forces that cannot be resolved by the historical solutions of migration, expansion, economic growth, and technology.*

The manifestations of stress in the world system are excessive population, rising pollution, and disparity in standards of living. But are growing population, pollution, and economic inequality causes or symptoms? Can they be ameliorated directly, or do the causes of stress lie elsewhere in the world system?

There is a growing awareness that past efforts to relieve stress in our social systems have often been, in retrospect, only efforts to suppress symptoms without altering the underlying causes. More and more, the world system is becoming tightly interrelated. An action in one sector of the system can produce consequences in another sector. Often the consequences are unintended and undesirable. We need to understand the ways in which the major factors are influencing one another on a world-wide scale if we are to have confidence that our actions will lead to improvement rather than to making matters worse.

Our knowledge and assumptions about the components of a system, even systems as complex as our social systems, can now be interrelated and examined through methods that have been developed in the last several decades. Such is done by organizing the individual concepts into a "model" that reveals the consequences and internal inconsistencies of our assumptions and fragments of knowledge. From such an examination can come a much improved understanding of the world system within which we are enmeshed.

This book sets forth a dynamic model of world scope, a model which interrelates population, capital investment, geographical space, natural resources, pollution, and food production. From these major sectors and their interactions

*See Peccei, References 8, 9, and 10.

appear to come the dynamics of change in the world system. Rising population creates pressures to increase industrialization, grow more food, and occupy more land. But more food, material goods, and land tend to encourage and permit larger populations. The growth in population, with its attendant industrialization and pollution, comes from circular processes in which each sector both enhances and feeds on other sectors. But in time, growth encounters limits set by nature. Land and natural resources become exhausted, and the pollution-dissipation capacity of the earth becomes overloaded.

The battle between the forces of growth and the restraints of nature may be resolved in a number of ways. Man, if he understands well enough and acts wisely, can choose a path out of the conflict of world pressures that is more favorable than present actions, attitudes, and policies portend. Such a path must be toward a non-growing and balanced condition of the world system. The challenge is to choose the best available transition from the past dynamics of growth to a future condition of world equilibrium.

Ever since Malthus stated his propositions relating population and food some 150 years ago, the validity of his assumption that food imposes an ultimate limit on population has been debated. The continued growth of population and the rise in the productivity of agriculture are often cited to refute Malthus. But it is undeniable that Malthus stated one ultimate barrier to unending population expansion. His assertion is not erroneous; it is merely incomplete.

Food supply may not be the first barrier to restrain rising population. Other forces within the world's socio-technological system may suppress further increase in population before starvation does.

Population, capital investment, pollution, food consumption, and standard of living have been growing exponentially throughout recorded history. Man has come to expect growth, to see it as the natural condition of human behavior, and to equate growth with "progress." We speak of the annual percentage growth in gross national product (GNP) and in population. Quantities that grow by a fixed percentage per year are exhibiting "exponential" growth. But exponential growth cannot continue indefinitely.

Pure exponential growth possesses the characteristic of behaving according to a "doubling time." Each fixed time interval shows a doubling of the relevant system variable. Exponential growth is treacherous and misleading. A system variable can continue through many doubling intervals without seeming to reach significant size. But then, in one or two more doubling periods, still following the same law of exponential growth, it suddenly seems to become overwhelming.

The psychological impact of exponential growth is seldom appreciated. Suppose that some ultimate physical limit stands in the way of a quantity that is growing exponentially. In all previous time before the limit is approached, the quantity is much smaller than the limit. The very existence of the limit may be unrealized. No clash between the growing quantity and the limit forces attention to the eventual pressures that must arise. Then suddenly, within one doubling interval, the quantity grows from half the limit to the limit. The stresses from

overexpansion become highly visible; they can no longer be ignored. If the pressures created by approach to the limit are not great enough to suppress growth, then growth continues until the limit has been overstepped far enough to generate forces sufficient to inhibit growth.

Exponential growth is only significant in comparison to some relevant limit. The power and nature of exponential growth are best appreciated through an example. Suppose, for purposes of illustration, that we start with a population of 1 million people and that the number doubles every 50 years. Figure 1-1 is a tabulation of population for the subsequent 700 years. In 700 years the population rises from 1 million to 16,384 million.

The values of Figure 1-1 have been plotted as the solid line on the graph of Figure 1-2. A "crisis level" at 8,000 million people has been arbitrarily chosen as the point beyond which the pressures from conflict between growth and some limit become severe. In drawing a chart as in Figure 1-2, we tend to pick the vertical scale so that the point of concern lies about halfway up the page. It is this choice of scales which makes growth appear so steep and sudden, and not any change in the "law of growth" that has been governing the system. To illustrate that exponential growth seems to surge up toward any ultimate limit regardless of its value, suppose that the "crisis level" in Figure 1-2 were at 800 million people instead of 8,000 million. A second vertical scale, chosen so that the "crisis level" comes at 800, is shown inside the figure. The dashed line is drawn through points that are again taken from the values in Figure 1-1 but, for the dashed line, are plotted to the inner vertical scale. A reduction of the "crisis level" by a factor of 10 has caused growth to impinge on that lower limit some 170 years sooner than for the solid curve. Otherwise the sudden rise and shape of the clash between growth and the limit are the same.

The surprise that we experience from exponential change comes, not from any sudden alteration in the pattern of growth, but instead from the pressures of

Years	Millions of people
0	1
50	2
100	4
150	8
200	16
250	32
300	64
350	128
400	256
450	512
500	1,024
550	2,048
600	4,096
650	8,192
700	16,384

Figure 1-1 Population growth during 700 years, with a doubling time of 50 years.