Global Population Blow-Up and After

The Demographic Revolution and Information Society

Sergey P. Kapitza

Report to the Club of Rome
Report to the Global Marshall Plan Initiative

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To Tanya,
our children
Feodor, Maria and Barbara,
and our grandchildren
Vera, Andrew, Sergey and Sasha

Contents

Foreword by the President of the Club of Rome

By presenting *Global Population Blow-up and After: The Demographic Revolution and Information Society* as a report, the Club of Rome is returning to what its founders set as the Club's main purpose: global problem studies. About 40 years ago, the Club of Rome commissioned *The Limits to Growth*. The book, written by Dennis Meadows and co-authors, develops Jay Forrester's original ideas on global modelling and was the first concerted attempt to describe the development of humanity on a global scale. In this ambitious effort, the main instrument of research was the computer and the material used to construct the model was extensive data that purportedly described the state of the world in great detail. This was probably the first decisive step to project global development in quantitative terms.

The study triggered a worldwide debate and the book was extensively and duly criticised. The study's legacy is the recognition of the global *problematique* looming on our common horizon. Now, four decades later, these problems have grown to be of paramount political importance and world leaders have to make very practical decisions on social, economic and environmental issues. At the same time, there is a conspicuous lack of global vision on the state of the world that could provide an understanding of the fundamental factors that drive our development. Kaptiza's book should be seen and assessed in this context.

In this novel study, which comes from the unexpected quarters of modern physics, mathematics, and complexity studies, a productive effort is made to work out a description of mankind's growth and development. The book traces the growth of human numbers throughout the ages and then makes population projects for the future. Demographic, historical, economic and sociological data provide the factual basis for working out the forces that ultimately drive development. The collective non-linear interaction responsible for growth, introduced by Kapitza, takes into account the unique human capacity to obtain and exchange generalised information, which is instrumental for development. This universal interaction effectively sums up all social, economic, industrial, cultural and biological factors that make up growth.

Unlike any other time in the history of humanity, the present explosive growth has culminated in revolutionary changes that are both rapid and profound. In less than a hundred years, mankind will cease measuring its progress in terms of numbers (people, kilowatts, butter, guns, etc.) and start assessing it in terms of quality of life. This is both a predicament and challenge that all of mankind, from the most advanced countries to those of the developing world, faces. By stepping into a world with a stabilized population, we will finally enter a new period of global development that will be less violent and inequitable than the past, posing a new global agenda.

In this interdisciplinary study, Kaptiza has not only crossed the unseen borders separating different areas of research, but has successfully bridged the major divide between the humanities and 'hard' sciences. This is an authoritative and original attempt to resolve the most complex and controversial issues facing humanity at this critical time of radical change. In explaining these ideas, Kapitza has done much to prove his point and deliver the message to the general reader.

H. R. H. Prince El Hasan bin Talal

Foreword by Professor Franz Josef Radermacher

Global Population Blow-Up and After by Sergey Kapitza, a report to the Club of Rome, is a most important and timely contribution. The topic of human population growth and development has been discussed by many authors in different contexts. Sergey Kapitza takes a new view position that is inspired by physics and systems analysis. He connects the insights of a number of areas of science to produce a novel and original picture.

It is well known that we are facing a population explosion and it cannot continue. To resolve this dilemma, Kapitza expands the scope of time right to the origins of mankind and interprets growth in terms of a self-similar process of development. He views the human system as a superorganism and argues that an inner law based on the exchange of knowledge drives its growth. Communication between humans, seen in general terms and assumed to ultimately engage everyone, is at the heart of this 'machine'. Knowledge and communication, properly understood, is the real nature of mankind. The capacity to co-operate and communicate makes mankind so successful in overcoming the limits faced by all other creatures — biotopes — in the growth of their numbers.

This interaction is similar to many-particle interactions studied in physics or social systems like mobile phone networks because communication grows quadratically. In Kapitza's work, these effects dominate the whole growth of mankind. This may be his most important contribution of this book, because it shows that humanity has grown as an information society for the last couple of million years.

Self-similar growth leads to the concept of a changing sense of time in history. This Eigen-time is determined by the cyclic addition to the human system of some 9 billion people with its appropriate information structure. In the beginning, this took about a million years, but now, after ten cycles, the time is compressed to some 40–50 years. As the human population grows, the inner Eigen-time of development gets shorter and shorter, and has presently hit its limit, which is set by the effective human lifespan.

This leads to another important observation by Kapitza. Until now, mankind has always managed to resolve problems that seemed to limit its growth. Can this accelerated development continue? Since 1972, in his great book, *The Divine Engineer,* Jacques Neirynck asks this question. According to Kapitza, the compression of time was not a problem in the past because the next generation could absorb new knowledge. Kaptiza has worked out a limit, which I have never seen discussed before. How can people adapt to the changes they face in their lifetime, which is currently on the same order as the Eigen-time of the system itself?

The central message of Neirynck's book is the rebound effect. New problems arise when old ones are solved, which ultimately creates the need for something new and leads to a phase transition in the language of physics. The need for change comes from the limits of past development, resources and pollution capacity. Kapitza argues that the decisive factors are the human mind, the systemic potential of mankind and the time it takes to adapt. In a sense, Jacques Neirynck and Sergey Kapitza express the same limit from different points of view. Nevertheless, and from both perspectives, a fundamental change is coming in the next decades.

I have studied some of the remaining options, but which will materialise in this near chaotic interim period is unclear. Sustainable development, a different kind of global order and issues that the Club of Rome deals with come to mind. Could a global eco-social market economy instead of free markets, turbo-capitalism, or a Global Marshall plan have the potential for stabilization and a better world? Or could the future be very different as eco-didactical and neo-hegemonial approaches or there is a total collapse of the biosphere? Nobody knows whether we will find a sustainable world or something else, e.g., starvation, all-out war, or over-population with hundreds of millions of people dying. Sergey Kapitza's analysis shows that a profound transformation is imminent. We will live through it and anticipating the challenge of change can help us to react accordingly.

Preface

The book describes world population growth as a global problem. I became involved with these issues through the Club of Rome and the Pugwash conferences on science and world affairs. After debates on global security and the menace of a nuclear war, it became obvious that population growth is the most pressing global problem. Approaching this problem, I realised that a new way had to be found to deal with this complex set of issues, in which history, economics and demography intersect. First of all mankind must be seen as a single evolving system with a long history. Without this broad vision of our past, it is impossible to understand the stresses and strains in the world as it passes through the greatest period of change ever or to gain insight into the crisis now facing humanity in so many dimensions of life.

My first book on the subject, *The General Theory of the Growth of Mankind: How Many People Have Lived, Are Living and Will Live on Earth,* was published in Russian by the Russian Academy of Sciences in 1999 and contains the results of the initial papers. In this edition, figures and content have been added to expand the main exposition and suggest directions for further research. Although the chapter on the demography of Russia is omitted, this edition provides the proper framework to analyse local and regional development.

Numbers express global population growth and mathematical modelling is used to search for general laws governing mankind's development. The book's approach is based on the following assumptions: the global population is an evolving system; systemic growth and development is driven by a collective non-linear global interaction; and this universal interaction is proportional to the square of the total population of the world.

The interaction, which is due to an exchange of generalised information, is propagated and multiplied mainly by language, is the primary function of the human mind and consciousness. It leads to acquired cultural inheritance and rapid, Lamarkian, social evolution that is distinct from biological, Darwinian evolution, which is transmitted genetically. This mode of development leads to the global population system's synchronous self-similar growth right from the early stages of humanity's origins. It is now culminating in the population explosion, during which human beings outnumber all comparable creatures by a hundred thousand times.

A general phenomenological approach to human history is developed in the first chapters. The approach goes beyond the agenda of demography because it has to be reconciled with ideas, concepts and results from history, economics, sociology and anthropology in order to construct the theory of mankind. The subject is really meta-economics, taking a step further into the economophysics of a social system far from equilibrium. In the network economy of a knowledge society, human culture, intelligence and consciousness are the primary factors of development.

The ideas of French historian Fernan Braudel on world history have greatly influenced my thinking. Braudel's studies on 'total history' are built on structures in time and space that are marked by changes in population. In regard to this study, the main variables are time and population. The population imperative drives growth and is non-linearly coupled with development. In the first approximation, space, migration and resources do not enter into the equation for growth as far as the population is limited to our planet. This simplifies the model, yet retains its relevance. After this set of ideas are developed using facts about the recent and distant past in the heart of the book, the future will be considered in the last chapters.

The global population is rapidly passing through the demographic transition and will stabilize at 10 to 12 billion. This demographic revolution is the most significant event in all human history. It will lead humanity to a new world, in which development is decoupled from growth, where the elderly will eventually outnumber the young and the global population will cease to grow. The restructuring of the age pyramid will inevitably lead to far-reaching changes in many aspects of life, including global and social security, economic priorities and the ethnic composition of countries. Developed countries are presently experiencing a profound decline in fertility. Despite their material wealth, these societies demographically do not deliver in their primary function — sustaining their numbers. This points to a crisis of mankind's priorities, which were once aimed at increasing power and population but are now shifting from quantity to increasing the quality of life.

In this work it has been recognized that the time scale of growth and development is not constant but changes. In global population dynamics, the scale of social time in the past expands by many orders of magnitude. Hence, history should be described in terms of temporal duration, which transforms social time and makes the past correspondingly closer. Russian historians Irina Savel'eva and Alexei Poletaev discuss these complex issues and their book, *History and Time: In Search of the Past,* was extremely helpful. As a result of this reasoning the test of the model is its ability to describe the past. Indeed, how can one look into the future without 'predicting the past'? Many modellers often disregard this possibility.

The non-linear dynamics of the global population system are described in mathematical terms by the concepts of scaling, self-organisation and chaos. All calculations can be found in the Appendix and may be omitted on first reading. Although the treatment is as simple as possible and I am sure Thomas Malthus, the first population modeller and the ninth wrangler at Cambridge in mathematics, could have followed them. Today I can only hope that social scientists will have the same sophistication as an aspiring clergyman in 18th century England did.

The bibliography, while in no way complete, contains sources from different fields that are usually beyond the scope of the non-specialist and the enlightened general reader. The references are arranged by date of publication and subdivided into sections to present the thesaurus of this interdisciplinary study. In the usage of mankind the term 'man' refers to our species *Homo.*

These studies would be impossible without discussions in very different audiences. I gave lectures on population theory at the

Moscow Institute for Physics and Technology, universities in Moscow and St. Petersburg, and at the JINR and CERN international centres for nuclear physics. I have also given lectures and seminars at the Russian Academy of Natural Sciences, the Kurchatov Institute for Atomic Energy, the Los Alamos National Laboratory, the Massachusetts Institute of Technology, the Santa Fe Institute, the World Economic Forum, Deutsche Bank, Cambridge's Department of Applied Mathematics and Theoretical Physics and the Global Security Program, and the Amsterdam, Groningen, Eindhoven, Dresden and Cottbus universities. My co-operation with Rand Europe in the Terra-2000 Project led to a discussion of these ideas, as did the Club of Rome. The Council of the Russian Academy of Sciences provided me with the unique opportunity for an in-depth discussion, leading to the general acceptance of this exercise in interdisciplinary research.

This work would have been impossible without the support from many colleagues and friends. First, I wish to thank the late Sergey Kurdyumov, the former director of the Keldysh Institute for Applied Mathematics, for his untiring co-operation, wholehearted interest and understanding. With him I shared the Government of Russia prize in 2002 for research in synergetics.

When the demographic problem was first discussed at the Keldysh Institute, it was recognised that the demographic explosion was a blow-up process propagated by a chain reaction. This opened up much of the advanced mathematics of non-linear phenomena, which now can be applied to global population dynamics. A memorable incident occurred when I gave a seminar to Professor Israel Gelfand, who then was at Rutgers University in the US. Giving that talk to the great mathematician reminded me of a piece of advice on how to choose the level of a presentation (the scale varies from the mother-in-law to John von Neumann and, in this case, it was Gelfand). He had worked at the Institute for Applied Mathematics in Moscow and remarked that my talk reminded him of discussions he had had with Andrei Sakharov on the intricate mathematics of blow-up physics. At that time, these processes were studied in connection with the most powerful nuclear explosions ever made. The remarkable physicist will also be remembered for his brave incursion into social issues of great complexity.

I would also like to thank Anatoly Vishnevsky, who introduced me to the world of demography, its methods and traditions. At first, demographers were reluctant to accept the generalised phenomenological approach because they believed it was impossible to interpret the demographic process in any other way than through a reductionist methodology. Demographer and sociologist Natalia Rimashevskaya and historian Alexander Myasnikov wrote the first critical reviews of this book that included an in-depth discussion of these ideas. Historians' acceptance of the main results and an invitation from Grigory Sevostianov, the editor of the *Journal of Modern and Recent History*, to contribute papers on this subject were significant steps in gaining wider recognition of these developments.

My invitation to contribute to the centenary issue of *Voprosy Economiki*, the principal Russian economics journal, indicated economists' acceptance of and interest in these ideas. Indeed, modern economophysics addresses the emerging knowledge society, in which culture, intelligence and consciousness are the primary factors of development. Support from Mihaljo Mesarovic, one of the founding members of The Club of Rome, was crucial. I owe much to Moscow Interbank Currency Exchange directors Alexander Zakharov, Alexander Potyomkin, and to Natalia Rumiantzeva and the members of the Nikitsky Club for their untiring support. My special thanks go to Global Marshall Plan Initiative and to Ecosocial Forum, Europe for publishing this edition and making it available. My thanks go to a group of inspiring German Rotarians of the Fellowship for Population and Development for their support, which made this publication possible: Michael Altwein, Jochen Klein, Hans Martin Scheuch, Jan Sombroek and Gerhard Ziener. I wish to thank Mikhail Ivanyushin for the layout of the book and Nicolas Smith for his great help editing the book after its initial publication by 'Nauka' and Olga Vasilenko for assistance and understanding.

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Chapter 1

Introduction

On all counts one should begin with the people.
Only then can we speak on the matter of things.
Fernand Braudel

1.1. Global Population Growth

This essay is about people and numbers, the number of people who lived in the past and will live in the future, the factors that determine growth and the extent that man can influence the future. The future cannot be foreseen without an understanding of the past because everything leading up to the present is inevitably connected with the future. Human history, which spans over a million years, must be examined and humanity be viewed as a single generalised object to understand fundamentally its growth and development.

In this book, mankind will be treated as a single system that, unlike traditional anthropological, demographic, economic and historical studies, ignores subdivisions like countries and regions. Humanity's development since the beginning will be considered by extending the temporal dimension to the origins of man. This significant departure from traditional methods allows the laws that determine population growth to be articulated because growth and development are being considered in quantitative terms over a vast period.

What does this broad approach with an extensive time scale that spans millions of years and encompasses all the people who have ever inhabited our planet really mean for each of us, our towns, our countries and where we live? Some think that local circumstances are sufficient to explain the facts of life, which is why many generalised studies seem to be out of place and irrelevant concerning what is happening here and now. All large-scale historical events, everything that occurred in our past, affect the life and well-being of everyone today. This has to be properly recognised and taken into account in everyday life because these consequences are often subtle and indirect. The profound messages of history may not be immediately obvious but they are meaningful. They deal with connections between generations, values and the very sense of our existence. These signals from the past are most in demand at a time of crisis. Today, the population of the world is incessantly growing and as new people, things and ideas appear others fade away and vanish into oblivion.

The stress on society and every person from the evolving circumstances of life is increasing because changes are occurring at an ever accelerating rate and these changes have a growing impact on the global population. At present after a million years of continuous growth, mankind has reached a threshold in this ongoing process of expansion as the world is making a rapid transition to a stable population. This is a profound change in the development of human civilisation. In less than a hundred years, the global population will stabilize at 10 to 12 billion, twice the size of the population in 1999.

The demographic transition is a revolution of such magnitude and significance that its full meaning can only be assessed by looking at it in the proper perspective. Although the demographic transition was discovered more than 50 years ago, the global implications of this transformation are only now being acknowledged. The demographic transition is a primary and objective factor in studies of modern history, theories of growth and development, assessments of national and social security, insurance and long-term investments. One of the objectives of this book is to provide a summary of the research on the global demographic transition done over the last decade [1–18].

This analysis is quantitative, as opposed to the multi-faceted descriptive approach employed in most social sciences. In history and anthropology, the focus of the majority of research has been to accurately describe the processes going on in society, countries and the world. A quantitative description is impossible without an understanding of these qualitative characteristics of the past and the present. In the following the concepts of physics and the methods of mathematics will be used to describe humanity's development in numerical terms. A quantitative description of growth and development is produced best when the process is viewed in general terms over a long period. This is similar to methods used in astronomy when astronomers' observations provide information for astrophysicists. In this book, descriptions from historians and anthropologists and the quantitative data from demographers provide the initial data for a quantitative analysis. There is, however, a basic difference between the world of inanimate matter and the life and evolution of mankind.

The observations of an astronomer and theories of an astrophysicist are on what is happening in distant alien worlds; the ideas and concepts of historians and anthropologists deal with humanity and are relevant to everyone. Most studies in the social sciences are influenced by the researchers' personal attitudes because they touch upon values, beliefs and ideas. By taking a more abstract and detached approach to demographic research, I hope to eliminate some of the inherent bias in studies of humanity.

To complicate matters further, all social studies are historical. All events and processes occurring in society only have a meaning when changes in time are taken into account. This evolutionary attitude of the humanities has to be kept in mind when comparing the approach of a natural scientist and a scientist engaged in social studies. This is also true of research in astrophysics, although all observations are made at the same time, but as different evolving objects are observed the changes during there evolution may be worked out. In our case mankind is unique. There is no other world or similar object to compare observations and theoretical calculations about man with.

These are most likely the reasons why a quantitative approach to population growth and the development of humanity has rarely been attempted. Methods that originated in the natural sciences, including methods based on systems analysis, were hardly ever used to describe population growth or historical processes. Instead, detailed descriptions of a specific event or occurrence were generalised. This approach by reducing the complexity of the world to the specifics of separate events in projections of the real world, has dominated modern thought. It has led to great difficulties and, according to some observers, to a crisis in the social sciences [92]. When humanity is viewed as a single entity then its properties and the processes are generalised in a holistic, integrated, approach not limited by reductionist reasoning.

Humanity should be studied as an entity because of the remarkable complexity of the global population system. The system is so interconnected and involved, constantly changing and evolving and has an infinite number of variations in time and space. The system seems to defy all attempts to find objective general laws based on the constancy of patterns of human behavior or to interpret these laws in terms of cause and effect. There are two reasons for this: first, the number of degrees of freedom and the number and variety of people that belong to a community or country is enormous, even if seen only in quantitative, statistically averaged terms; and second, the processes occurring in these systems are extremely varied. When literally everything has to be taken into account, the interdependence of all of the factors makes an approach based on a detailed cause and effect treatment essentially impossible even if broad generalisations are made.

In demography, birth and death rates are considered to be the primary data which express growth. The approach excludes the fact that everything (agriculture, industry, housing, transport, education, medicine, science, technology, finance, communication, religion, art, the media, entertainment, armies, wars, crime, police, etc.) has an effect on population growth. All of this is taking place and has happened in time throughout history, which includes the grand epochs seen by the anthropologists as well as the daily events recorded by journalists. Each factor has a different effect and it is possible to rank the influence of each, but the remarkable complexity is clear. Further complications stem from the fact that each individual, as a member of society, is a system of immense and poorly understood complexity of body and soul.

However, complexity itself opens an opportunity in understanding the intricate nature of the population system. For complexity has become a significant concept in modern developments in physics and non-linear systems mechanics. The specific meaning of complexity has developed from the intuitive idea of the complex composition and behavior of a system. A generalised approach is possible because effective methods to deal with complex systems have been developed. These methods originated in physics and initially were used for simple and well-defined problems. These now can serve as intellectual models for the behavior of more complex systems. Following this logic, new ways of studying systems have been worked out. In addition to new results and data, new terms and concepts have been introduced, which are a useful product of abstruse theoretical constructs. Currently, more and more applications are being found for this novel and powerful non-linear approach.

This new way of treating complex systems was derived from mathematical theories and connects to the real world in terms of complexity and thresholds, chaos and bifurcations, guided by chance and necessity. Non-linear studies have become one of the most fascinating and rapidly developing subjects in modern physics. The approach has spread beyond physics and is finding its way into the social sciences. How the approach has been adapted in fields as diverse as psychology, economics, history and linguistics is described by Gleik [147] and Waldrop [153]. Oddly, non-linear methods have never been properly applied to population studies. On the other hand, unfortunately, the non-linear approach has been used by some who detract from the development of the field and only add confusion.

1.2. Dynamical Approach to Social Studies

In past studies, history was described as a sequence of events and the scale of change, in quantitative terms, was ignored. Instead of only being used to depict change, numbers must also be used to measure development. Studies of humanity should really begin with population growth because the size of a population and how it changes are the real measure of development. That is why data describing population growth will be used to derive the primary expression of mankind's development on a global scale.

The formal analysis and mathematics in this book took less effort than finding connections with facts from demography and concepts of history, archaeology and anthropology. For a physicist, this approach was very exciting and led to a new way of looking at the development of humanity. The broader implications of this work became clear after this new vision was interpreted through a historical and socially relevant lens as it evolved into a real theory and acquired a life and meaning of its own.

This step was time consuming and difficult because attempts to explain the reasons for growth had to be abandoned initially and a general understanding was achieved only after the overall description was produced. Then it became possible to discern, interpret the basic principles of systemic growth, although these general methods have rarely been used to describe the total human experience as far as the reductionist approach dominates most thought. The past needs to be taken into account before the present can be described or the future charted, as the past is the factual test case of any scientific and objective treatment.

An interdisciplinary understanding has to be developed on both sides of the conceptual divide. Social scientists must also gain an understanding of these methods and here I am indebted to my colleagues in other fields. One of the most difficult aspects of the project was to reconcile and produce a correspondence between the ideas and concepts of two different intellectual cultures: physics and mathematics, and social and historical studies. Real progress is only possible when an intimate interaction between theory, high theory, the object of study and the facts of history occurs. This study is an attempt, or rather an exercise, at establishing such a mutual understanding.

This type of interdisciplinary understanding should first be reached in the field of demography as it deals with numbers. Apart from justifying the treatment of humanity as a whole and extending the time scale of the study, it became necessary to show the interaction between the linear piecemeal approach of demography and non-linear theory. The next significant development was to identify major cycles, which are recognised in anthropology and history, in the model.

This step led to a reappraisal of the meaning of time in human history. Long sought for by historians and philosophers, the transformation of time can now be interpreted in terms of population dynamics. A fundamental understanding of the nature of time in history is one of the significant conceptual outcomes of this study. The compression of time in history, which culminates in the crisis of the demographic transition, is the turning point in the development of humanity when the shortening of the time scale can go no further as it is limited by the human life span.

A re-entrant pattern of discourse is pursued when developing these ideas by going from a mathematical model to demographic data and back. Passing along this loop, the model finally evolves into a theory. The constructs of the theory are gradually consolidated into a non-contradictory set of arguments that eventually takes on a life of its own. This development is stimulating because the inherent logic of the mathematics of the model leads to new connections and greater insight into models of the real world.

A concept, central to the theory, is the collective information based interaction driving the development of mankind, a peculiar feature of *Homo sapiens*. In nature, all creatures transfer genetic information between generations. As distinct from other animals, human beings have the capacity to transfer information by social inheritance. Human beings transfer information through speech and language, and express the information through intelligence and consciousness as social phenomena. These qualities make man a very singular animal and determine mankind's remarkable population growth over the last million years. Now this explosive growth has come to an abrupt end: the discontinuity of the demographic revolution, challenging our growth and development. We have reached a turning point when our ideas and understanding can determine our future development as never before. That is why, at a critical time, these issues become of great practical importance and have to be faced with full responsibility in reformulating a new set of ideas in the emerging knowledge society.

In dealing with the necessity of having an objective attitude on these sensitive issues, an instructive episode occurred in 1991 when the *Agenda for Science, for Environment and Development* *into the 21st Century* was commissioned by the ICSU and UNESCO. A message from the world scientific community was to be addressed to a special session on the environment in Rio de Janeiro in 1992. Experts were invited to the International Institute for Applied Systems Analysis (IIASA) to discuss the content of the book and I was to contribute on the public's perception of science.

We met at the beautiful Summer Palace of Maria-Theresa in Laxenburg, near Vienna, and the only topic missing from the agenda was population. This prompted me to ask the chairman about the omission. He did not respond and a coffee break was announced. During the intermission, I was told that demography should not be discussed. As the chairman told me this, he pointed to the ceiling and said the topic was declared to be off limits. Although I felt somewhat like mischievous student facing his headmaster, I tried to speak out, but was told that developing countries and religious bodies had to be taken into consideration... That was the first time I had met such a 'no nonsense' put down. Luckily, Sir Anthony Epstein, the vice-president of The Royal Society of London, overheard this conversation. He intervened and said that Kapitza was right and that demography certainly should be discussed.

After support from the most authoritative academy, the editorial board had to change its mind and *Agenda-21* opened with a carefully written paper by Arispe, Constanza and Lutz on world population projections [66]. Later Senator Al Gore wrote on these matters [119], the Statement of The Royal Society of London and US National Academy of Sciences was published [70], and then the Statement of the Population Summit of the world's scientific academies were signed in 1993 in New Delhi, breaking ground on this sensitive subject [71].

1.3. The Statistical Nature of the Demographic Problem

When humanity is viewed as a single system, averages are used as data instead of precise figures. Averages are widely used in social sciences to describe the age of a population, population density, or income. For example, statistics can be used to rank towns in terms of population. In the ranking process, the details about a town or village are lost in the sequence of all relevant participants. While ranking towns is rather abstract, ranking people in a society according to income shows the fundamental inequities in a community. It describes the distribution of wealth and, in objective terms, can show the profound differences splitting a society. These divisions lead to personal stresses and strains in the social and economic fabric of a country that could finally excite deep feelings and political unrest.

In social studies, average representations are separate objects that have their own meaning. When dealing with many people and complex systems, the result of an average of all that is taking place, should be used. In the social sciences, the use of statistical data is widespread and used to describe birth and death rates, life expectancy, age distribution and migration. Statistics has two distinct meanings. It can mean the assembly of all raw data — demographic statistics. It can also be used in the context of a statistical approach, which is a model or theory that uses statistically averaged data and an aggregated representation of processes to describe what is going on in a system.

Critics of the statistical approach cite the average body temperature of patients in a hospital as an example of the impersonal nature of this procedure. For an individual patient, the average temperature is of little interest. But the data is useful to the hospital administration, however, because it could indicate an epidemic and be a signal to quarantine the hospital. While personally inconvenient for each patient, quarantine would be the correct decision. This illustrates how the appraisal of situations with people involved depends on the scale of the event and, as a simple example, shows how relative judgements and reactions can be. It demonstrates the difference of scaling in an interactive system and, at the same time, raises profound moral issues. Finally, a person's body temperature is an integral parameter that is the average of many interconnected processes going on in the human body, a complex and interactive system. At the same time it is a parameter which is simple to measure and interpret.

In social studies, a constant difficulty is to maintain the proper scale in assessing events, and attempts to immediately provide local explanations of developments are misplaced. Indeed, it is easy to find counter-examples that seem to disprove any statistically valid statement. But general features should be illustrated by concrete examples and observations. The art of discerning and interpreting the facts of everyday life through a general theory is one of the most demanding aspects of social studies. A social scientist's ability to do this is the mark of his or her real and deep understanding.

The tradition of using straightforward explanations is old. Some trace its origins to when natural phenomena were explained by ascribing them to various local, and often quite specialised, deities. As monotheistic belief systems developed, a single, omniscient and omnipotent God was ultimately deemed responsible for all that is happening. The evolution of science followed the same pattern and the transformation began in earnest with Newton, when the success of mechanics in describing the Solar system signalled the triumph of this approach. The development of mechanics in the 18th century is the classic example of mechanistic, reductionist reasoning. It is epitomised in Newton's dictum '*hypothesis non fingo*' (I do not invent the hypothesis), meaning that he refrains from vague generalisations. The Newtonian ideal was to produce definite and clear-cut results from first principles. The results demonstrated the power of this new method, which had a profound influence on the development of human thought. It set an example of a deterministic world with an orderly pattern of behavior, and in this well organised world, cause and effect are identified in everything that happens [135].

Future developments in physics have shown that the phenomenological approach is just as important and productive. In this case, the average behavior of systems is the object of study and laws describing these systems are sought. This approach led to a phenomenology for dealing with complex phenomena that a detailed, reductionist approach is unable to explain. A transition from a microscopic to a macroscopic scale is only possible in special cases. Later, it became obvious that a description of the systemic behavior of a complex world was only possible in probabilistic terms.

This approach was first developed and used in theoretical physics. In cases when the same phenomenon is explained by both methods, it becomes clear that the differences in the approaches are in terms of scale. Some philosophers of science argue that these two approaches are ultimately just different manifestations of the same method. Newton introduced the concept of universal gravity as a force that governs the motions of gravitating masses, and postulated its properties without explaining its nature. In fact, a fundamental and unified explanation is still being sought to describe the nature of gravity, where not much has changed since the days of Newton or even Einstein.

The methods used in history differ greatly from the methods of the natural sciences, although 19th century historians, influenced by the progress of natural sciences, searched for general principles of historic development. Now, most of these romantic generalisations have been replaced by pragmatic and practical suggestions. Therefore, most social sciences are dominated by the reductionist approach, which has led to the break up of the social sciences. Economist Friedrich von Hayek appropriately remarks:

> The disintegration of social inquiry into specialised disciplines leads to the exclusion of the most essential questions, which are relegated disdainfully to the margins of a vague social philosophy.

In spite of this, there are currently attempts to revisit the grand theories in the social sciences to search for a deeper understanding [92]. Historians striving to develop a large-scale picture of history have repeatedly stated that humanity should be treated as an entity. Russian historian Nicolai Konrad writes in his collected essays, *West and East*:

> In this case all our knowledge of the past in connection with what our current epoch shows in relation to this past and future allows us to reach an understanding of the pattern of the history of humanity and in that way to work out a philosophical concept of history. This can be done only by taking into account the history of all mankind and not of any group of peoples or countries...

> Facts, showing that the history of mankind is the history of all humanity and not of isolated people and countries, that an understanding of the historical process may be reached only by looking at the history of mankind, these facts abound in all domains of study. All history is full of them [87].

Braudel focused on 'total' history and he comments on the works of a well-known German economist in a paper on demography and social sciences:

> Ernst Wagemann has all reasons to give an important lesson to historians and to all, who are concerned with social sciences: there are no substantial truths concerning humans, except on a global level [90].

At this point the distinction between world and global entities should be clarified, as it has been discussed by Immanuel Wallerstein in *The Modern World System* [96] and then by Manuel Castells. The difference is in the extent to which the world economy or population can be treated as an interactive system rather than a mere collection of independent objects. Thus Castells defines:

> The global economy as an economy whose core components have institutional, organizational, and technological capacity to work as a unit in real time, or in chosen time, on a planetary scale [102].

The difference is the extent to which the global population or economy can be treated as an interactive system depends on the time scale. We shall see that as the time scale increases in the past, the systemic effective time scale is of the order of magnitude of the age of the population system reckoned from year 2000.

In historical studies, the past is seen as a sequence of events, processes and personalities and most historical studies describe what occurred with qualitative and descriptive details inevitably preceding their quantitative expression. Nevertheless, sooner or later history will have to be reconciled with numbers to express, synthesise and interpret history of the human population system. This is the real meaning of our work when a quantitative approach is developed, based on a mathematical model and using the data of global demography — the number of people in the world as a starting point of our analysis.

1.4. From a Qualitative Description to a Quantitative Analysis

Rather than providing a universal definition of a system, based on a formalized systems analysis, the problem will be articulated as it is done in physics. As the growth of a system is traced in time, the main issue is what parameter or parameters should be used. In other words, any quantitative model has to begin by plotting a parameter of growth as a function of time.

Dates are the universal numbers in history. Through the detailed and extensive procedures of chronology, a well-established sequence of dates has been produced. For example, methods based on physical phenomena like carbon dating have become an important auxiliary instrument in studies of the past. Carbon dating can be used to date a splinter of wood, a thread of cloth, a scrap of charcoal from a wall painting in a cave, bones or the ashes of a fire that burnt thousands of years ago. By cross-checking data, a generally accepted universal timeline that extends for millions of years was worked out by generations of historians and anthropologists [24, 25, 28 and 29].

I recall a visit to the main cathedral of the Armenian Church at the foot of Mount Ararat in Echmiadzin, Armenia. The most remarkable relic in the cathedral was a piece of dark wood in a silver frame hanging on a wall in the vault of the treasury — a fragment of Noah's Ark. I asked the bishop, who was kindly taking us around, whether he could give us a little piece of the wood in order to carbon date it. His immediate response was: 'That would be a fine way to test your method.' This is a modern illustration of Tertullian's dictum, '*credo quia impossibile*' (I believe, since it is impossible), pronounced in the 4th century CE to settle disputes between faith and science. This point should still be kept in mind.

Determining a measure for development has led to significant difficulties. In economics, for example, finding a common unit for such diverse factors as labour, rent, resources and information has been difficult. If prices can be set at any given moment in the presence of a market, how can one convert 30 pieces of silver into

Table 1.1. Structure and dynamics of the population of the world. UN data [74]

Region	Population billions 1997	2025	2050	Births per 1000	Deaths per 1000	Natural Growth % year
World	5.84	8.04	8.9	24	9	1.5
Developed	1.18	1.22	1.15	11	10	0.1
Developing	5.34	7.72	8.65	27	9	1.8

Region	TFR	Doubling time, years	Life expectancy, years	Urbanization, %	Age % Composition <15	>65
World	3.0	47	66	43	32	7
Developed	1.6	560	75	74	20	14
Developing	3.4	38	63	36	35	5

US dollars? What does the cost of information obtained mean today and what did it mean 2,000 years ago in the eastern provinces of the Roman Empire? Because of the disparate factors and the enormity of the period being studied, a realistic quantitative parameter for the global economy must be found. But, as it was remarked in a discussion, a piece of silver was what a labourer earned in a week 2,000 years ago. This observation shows how a common economic denominator can be reached. Passing to a still greater time scale and encompassing the whole world, the measure of things has to be found by directly coupling human numbers with the economy and development.

The number of people is the only other parameter as universal as time. It can be applied to any moment in the past and population data is referred to at all levels of the population system. When two people meet for the first time, one of the first questions asked is: ‘How many children do you have?’ Population statistics are of general interest. In the United States, road signs marking a town or city on a highway usually include the name of the town and the population. When travelling to another country, one usually attempts to learn the size of the country’s population. Imagine an

Table 1.2 World population *N* in steps of one billion and its growth in time

N billion	1	2	3	4	5	6	7	8
T year	1830	1930	1960	1975	1988	2000	2013	2028
D*T* years	1 million	100	30	15	13	12	13	15

extraterrestrial coming to Earth for the first time. Its first question inevitably would be: 'How many people live here?'

As a child, I was taught that 2 billion people lived in the world. Now there are 6 billion: my life has coincided with the most rapid increase of human numbers in history. Nevertheless, the size of the population in the past is largely ignored. In 1700, the global population was ten times less than it is today. Few people care how many people lived in Russia under Peter the Great, although most Russians know the dates of his reign. Population ratios in time are quite stable and Russia's current population is approximately ten times greater than it was at the beginning of the 1700s.

The best way to look at how the global population is changing is to view the change over time in terms of billions. The global population first reached 1 billion only in 1830. In 1930, 100 years later, it reached 2 billion. In 1960, 30 years later, it reached 3 billion. In 1975, 12 years later, it reached 5 billion and in 1999, 12 years later, it reached 6 billion. The population growth rate reached its maximum in 2000 and is now in decline. In 2025, the population is expected to be about 8 billion and by the middle of this century it is expected to reach 9.5 billion and then eventually level off at 10 to 12 billion. As the steps in time around 2000 are practically the same, the rate near its maximum does not really change. In other words, the population passes through the transition following a linear law.

The number of people in the world has the same meaning today, as it did 2,000 years ago when a 100 million people inhabited the planet or 1.6 million years ago, the Lower Palaeolithic, when approximately 100,000 people lived. These numbers, however limited in accuracy, provide a well-defined answer to the gross pattern of human development. Global demographic data clearly is a quantitative measurement of not only the size, but the state of mankind in the past and present. In other words, the number of people expresses the sum of all economic, social and cultural activities and is the product of all human development. Recognising this as a measure of humanity is not as simple as it may seem, but it is fully justified. These numbers can then be interpreted by a theory of mankind, if such a description is not only possible, but also attainable.

1.5. Population Explosion and the Demographic Transition

Every day we witness the dynamics of population growth through the number of children in our families, communities and cities. Every second, 21 people are born and 18 die, a net gain of three people and every day the population increases by 220,000 people. The growth rate has been incessantly rising and is currently so high, approaching 80–87 million people a year that it was viewed as a population explosion.

Demographic data is usually categorized by country or region. Population data for the main regions of the world show general growth trends and variations in patterns of development. The net global population growth follows a more regular pattern and culminates in the rapid blow-up of the population explosion.

The expanding population demands more and more food and energy, requires greater consumption of mineral resources and exerts increasing pressure on the environment. If extrapolated into the future, the concept of increasing and seemingly unlimited growth leads to frightening forecasts and even apocalyptic scenarios [61]. It is therefore essential to really understand what determines population growth and then develop projections for the future.

In spite of all the drama surrounding the population explosion, what is really important is that we are currently passing through the demographic transition. This phenomenon occurs in every population and is characterised by a long-term rise in the growth rate followed by a rapid decrease in growth and the eventual

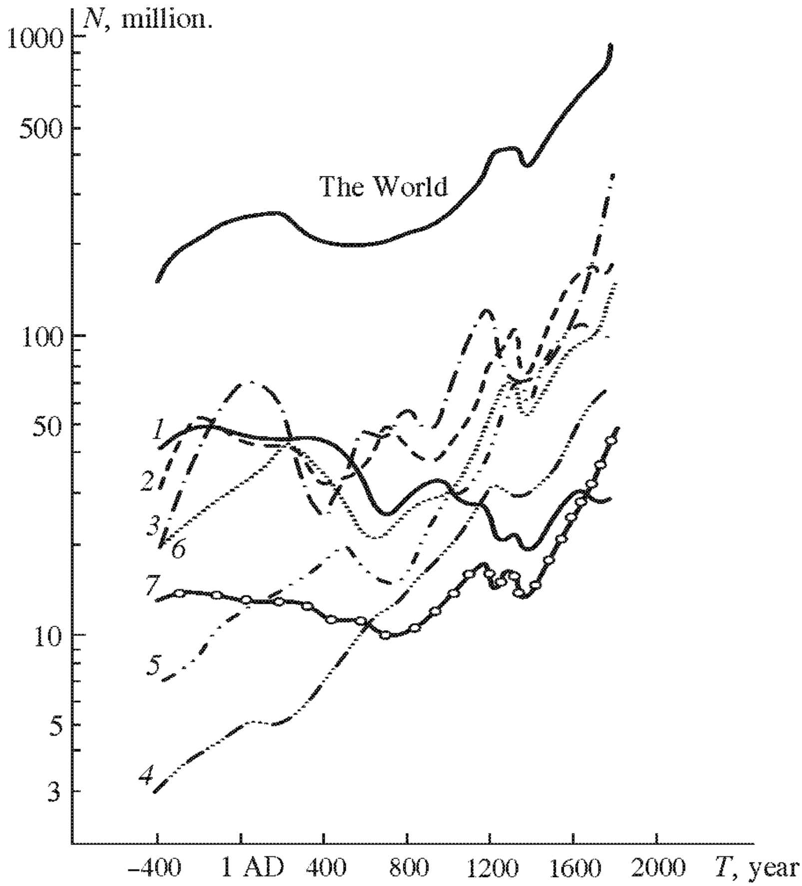


Figure 1.1. Regional population growth from 400 BC to 1800 AD [56]

1 — South East Asia, 2 — India, 3 — China, 4 — rest of Asia, 5 — Africa, 6 — Europe (without Russia), 7 — USSR

stabilization of the population. This transition has occurred in all developed countries and is currently happening on a global scale. The demographic transition is accompanied by a general increase in economic growth and urbanisation. In the final stages of the transition, the population begins to age — the elderly outnumber the young.

The global demographic revolution has a direct effect on different regions and countries. It will ultimately affect the

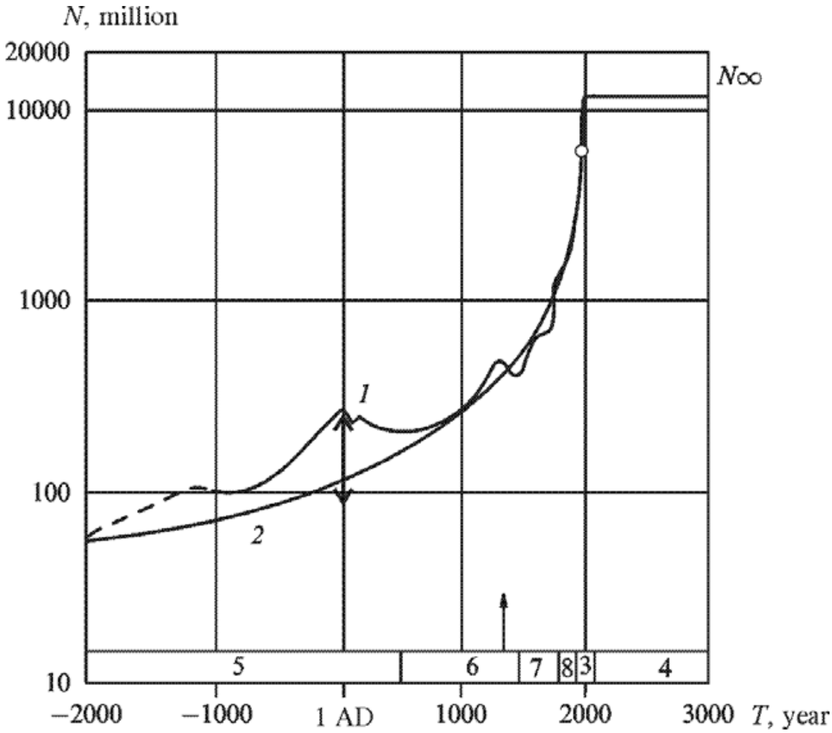


Figure 1.2. World population from 2000 BC to 3000 AD. Limit N_∞ = 12 billions

1 — data of Biraben [54]. 2 — blow up growth, 3 — demographic transition, 4 — stabilized population, 5 — Ancient world, 6 — Middle Ages, 7 — Modernity, 8 — Recent history, ↑ — the Plague, ◦ — 1995. ↕— error.
At no time growth is exponential. As the demographic transition is approached, the time of history and development is compressed, up to an abrupt switch to a stable population.

development and stability of all societies. Globally, it is progressing much faster than it did in Europe, where the process began in the 18th century in France where the transition was first discovered. In the modern interconnected and interdependent world, this abrupt transition will end with the 21st century.

1.6. Models in Demography

Population data for the main regions of the world show general growth trends as well as variations in patterns of development. The net global population growth follows a more regular pattern and culminates in the rapid blow-up of the population explosion.

Demography provides a plethora of data and numbers that describe the population of every country at different times. The data include distributions by age and sex, the statistics of life and death and patterns of migration. This data can be used to make population predictions for the next couple of generations. These projections can be extremely detailed but also misleading. For example, according to the UN Population Division, 37,000 men older than 80 are expected to live in Burkina Faso in 2025 [65]. Although, given the unpredictable nature of the environment and governments, especially in Africa, these estimates are rather unreliable. Global population trends can be estimated, despite this uncertainty, by compiling the population data from every country in the world. One of the difficulties in assessing growth is accounting for the factors that determine it. The interconnectedness of most of the factors determining the growth of a population and illustrates the complexity of the human system is shown in Fig. 1.3. If numbers, representing the coefficients coupling the main items of this diagram, are introduced, the network shown in Fig. 1.4 is produced. The level of a woman's education is the most significant factor in the number of children she will give birth to. This indicates the direct contribution of cultural factors to the growth rate. In fact, this is to become the critical issue for humanity to sustain its numbers in the future.

It is unlikely that a further expansion of this approach will lead to any reasonable results that describe global population growth. The more in-depth the analysis of the system is, the more complicated and interconnected it gets. Therefore, it is futile to construct extended models with many parameters that are based on a large assembly of primary data. In a complex system, all the connections are not only interdependent, but most are time dependent and non-linear. Even in a linear approximation, the coupling between various entries in these diagrams should be expressed by integro-

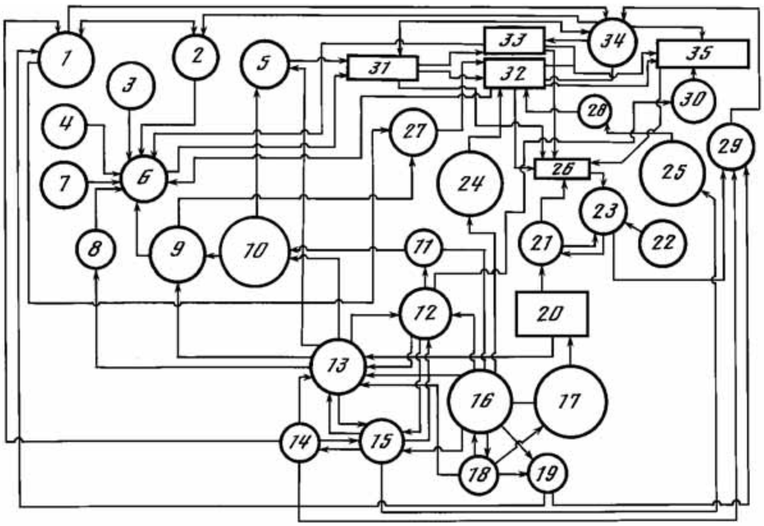


Figure 1.3. Factors determining population growth [42]

1 — health care, 2 — longevity, 3 — fecundity, 4 — infant mortality, 5 — infanticide, 6 — birth rate, 7 — sterility, 8 — age of marriage, 9 — prenatal birth control, 10 — optimal living space, 11 — occupation of women, 12 — group mobility, 13 — group size, 14 — standard of living, 15 — socio-cultural environment and education, 16 — industry, 17 — productivity, 18 — resources, 19 — diet, 20 — potential maximum of population, 21 — migration, 22 — territory, 23 — population density, 24 — professional mortality, 25 — militarism, 26 — population, 27 — maternal mortality, 28 — war, 29 — disease and epidemics, 30 — killing the old, 31 — pre-reproductive population, 32 — men and 33 — women of reproductive age, 34 — natural death rate, 35 — post-reproductive population

differential operators that show the dependence of the parameters on their rate of change and delay in reaction.

Most of these attempts begin with numbers and linear mathematics. Despite their practical usefulness, demographers' extrapolations are limited in time and space and contained by the geographical boarders of countries and regions. Demographers are further bound by their professional responsibility and traditionally refrain, as did Newton, from 'inventing hypotheses'. That is probably why demographers are rather reluctant to accept the necessity

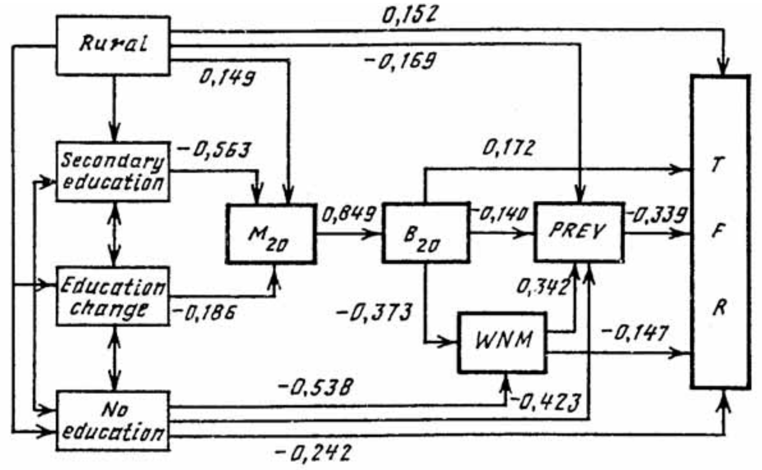


Figure 1.4. Network describing the factors affecting fertility and population growth

TFR — the total fertility rate, WNM — want no more children [74]

of exploring a phenomenological, holistic approach. Therefore, the phenomenological treatment should not be viewed as an extension of standard methods, but rather as a complimentary approach to demography in finding a new way of dealing with the complexity of the growth and development of mankind.

1.7. The Complexity of Systems and Aggregating Data

To address this 'curse of complexity', American economist and Nobel Prize winner Herbert Simon notes:

> Forty years of experience in modelling complex systems on computers, which every year have grown larger and faster, have taught us that brute force does not carry us along a royal road to understanding such systems... modeling, then calls for some basic principles to manage this complexity.

The alternative to standard demographic methods and global modeling is to pursue a systemic treatment of the global population and consider it as a non-linear evolving and self-organising system. This assumption is the initial condition for formulating a mathematical model. All local details and specifics of development have to be aggregated into the phenomenology of growth of the whole system. In fact, this is already done in demography, but on a smaller scale — by country or region. The demographics of France or Britain express the rather uniform population of these countries in a single number, about 100 million people. However, in the cases of India and China, which are countries with a great variety of ethnic groups at very different stages of economic development, demographic data already sum up 1/6 and 1/5 of the global population. The next step is to go to the level of the global population and this conceptual step is not especially great in terms of the degree of aggregation.

A greater conceptual difficulty is to move from the temporal scale of one or two generations to a scale that includes the entire history of mankind. This is a large step and a new sense of time must be developed. A more detailed study of the meaning of time over the course of systemic development shows that the transition to a new time scale is not as great as it may seem at first. By taking into account the non-uniform pattern of temporal changes, the past becomes much closer than it would if the distance into the past were viewed on a uniform time scale. Aggregation in terms of population and time is a natural way of developing a framework to discuss the dynamics of the global population system.

Short-term and reductionist thinking must be avoided to develop a global attitude and view humanity as a system. In this case, all short-term and local processes are averaged out and only the gross features of mankind's development are left. At the same time, all cause-and-effect modes of describing the system are merged into a single global interaction that is responsible for the growth of the population of the world. This leads to a consistent description of the development of mankind, where the total number of people in the world becomes the main parameter of growth.

Unfortunately, the global population was never really seen as a meaningful object in demography because it seemed impossible to trace and identify the reasons for changes in the global demographics. Most traditional studies in demography attempt to interpret demographic data in terms of the social and economic factors that determine the growth of human numbers. These results were used to explain growth and provided the basis for advice to governments on demographic policies. The following discussion written in 1966 by the dean of French demographers, Alfred Sauvy, is of interest:

> For a long time 'global population' merely referred to a sum, an idle addition. It merely indicated the relative importance of each country in the world, and even such comparisons were of limited interest, since one knew very little about the most populated countries in the Far East. In the last few years the 'problem of the population of the world' has been posed, usually meaning the 'overpopulation of the world'. Those who mention it usually wish to point out the excessive growth of the human species and the risks this entails.
>
> In fact, there is so little solidarity between countries that this problem has never really been put properly. Not only does the Communist world pursue its own isolated line, one might even say a double line, but also even in the capitalist world migration are slowed down by frontiers. Power is broken up into geographical units and it is only inside each individual country that real problems of population exist. Timid mentions are made of a western European population, because there are the beginnings of solidarity between the various countries here.
>
> For the time being, there is no more a problem of world population than there is a world budget. This topic is therefore an anticipatory one. It could be formulated thus: if men were strongly linked together, for instance by a world government, there would be problems of food, space, and employment, due to the surplus of the population for the resources available. The wish for, and perhaps even more the fear of, solidarity brings about the idea of the world population. It is fatally a Malthusian view, since half the people in the world are hungry. The well-fed inhabitant of a developed country feels no emotion at all at the thought that part of the planet is uninhabited; he is more struck by the other, overpopulated part. One is thus led to anticipate on the future and define the problems likely to arise from the pooling resources, or even from mere collaboration: but the Malthusian view easily urges very

> complex solutions. Some countries would find themselves accused of overpopulation, others would be asked to make room for the less fortunate men. Such a view even lacks any internal logic to commend it. As long as the national units subsist as they do now, everyone's life is necessary to society in general. Centres of decay would be dangerous for all. There is therefore a 'false problem of the world population'. A problem is not in fact true or false in itself, but it can be badly defined, and this is the case here [51].

The difficulties arising from the trend towards a narrow and specialised attitude to these problems have been expressed in the *Report of the Independent Committee on Population and Development:*

> An increasing fragmentation of knowledge and expertise, combined with a deepening specialisation among professionals, has prevented interweaving of population and development issues [125].

Global statistics contain a clue to formulating the quantitative laws that describe the dynamics of world population growth. The global population follows an inherent pattern of development that, within limits, is independent of external constraints or resources. This has led to the concept of the population imperative, the general principle of growth and development, and the formulation of a connection between growth and development by an information-moderated generalised interaction. In the following chapters, this generalized approach is studied in terms of time and population using methods from the physics of complex systems. The extent to which the concept of a system can be meaningfully applied to the total population of the world and whether the process of growth is statistically regular and historically predictable should be considered first.

Chapter 2

Global Population as a System

Know then thyself,
presume not God to scan;
The proper study of mankind is man.
Alexander Pope

2.1. The Physics of Systems

The concept of a system originated in mechanics, where it has a well-defined meaning. The first and probably the best example of a system is the Solar system. This system is dominated by the Sun, the central body. The celestial mechanics of the Solar System can be described in remarkable detail because there are only a dozen gravitating bodies and the law of interaction within the system is well defined. Still, the mathematical expression that describes the Solar System requires tens of thousands of terms. The understanding gained through and the accuracy of the predictions made using the celestial mechanics of the Solar System is impressive. The discovery of Neptune became the ultimate triumph of mechanics and is one of the reasons why classical mechanics has had a profound impact on all other sciences.

The strength of a system's internal interactions holds the system together and a system's proximity to other systems determines the effect of the interactions between the system and the surrounding matter. In the Solar System, all motion is determined by the force of the gravitational interaction between the Sun and the planets and between the planets themselves because the system is, to a great extent, isolated from all other stars.

It is difficult, if not impossible, to define the interactions in complex systems in any detail. Nevertheless, the strength of interactions can be assessed, without going into a detail consideration of the nature of the forces concerned, by the time it takes to change a system. Then changes in a system can determine interactions and the effect interactions have on the system. Therefore, it is still possible to apply the concepts of systems dynamics to complex social systems, when a reductionist interpretation of the nature of an interaction is not a requisite for determining its effect and strength. Thus a universal way to measure the power or strength of an interaction, without going into an analysis of a system's mechanics, is by assessing the time it takes for a change to happen.

Even in a simple system like the Solar system, where reductionism should ultimately work to test the system's long-term stability, the precision of planetary forecasts is limited because comprehensive calculations are, in principle, limited by the accuracy of the initial conditions to some tens of millions of years, much less than the 4.6 billion years Earth has existed. Even in the case of the Solar System, an ideal piece of heavenly clockwork, the accuracy of the mechanical model its power is finite. Only recent development of sophisticated and abstract analytical methods based on the general properties of dynamic systems rather than detailed calculations of the motions of planetary bodies have made it possible to determine the long-term behavior of the Solar System. This is an instructive example of the potential of a generalized approach to a problem of the evolution of a complex system, where the elementary interactions are well-known and expressed by simple laws, but there predictive power in a reductionist framework is limited.

After mechanics, thermodynamics was developed and the power and potential of the phenomenological approach was recognized. New generalized parameters for systems were introduced like temperature and pressure for gases. The gas laws are indeed quite simple. In the ideal gas model, the relationship between pressure, temperature and density are that of proportionality. When the pressure of a gas is doubled at a constant temperature, its density also doubles. Gases were the first systems to be studied by thermodynamics, are simple many-particle bodies composed of a myriad of molecules. Austrian physicist Ludwig Boltzmann made a significant breakthrough when he established the connection between the mechanics of the motion of gas molecules and the phenomenological treatment of thermodynamics. This led to the kinetic theory of gases and the development of statistical physics. The proportionality of the relevant properties is expressed by laws with no inherent parameters that specifically govern the relative state of a gas. These laws are an example of scaling and are a fundamental aspect of changes in complex systems. In regard to population growth scaling means that in a given period all stages of growth and development follow the same pattern of change, expressing the self-similarity of the entire process of growth. It then became clear that much could be learned by using an analogy with gases as a generalized model for the population system, instead of an in-depth reductionist treatment. Many insights into how the system functions can be derived by properly choosing the characteristics of interactions. This became a model of a generalized method, an approach that can be used to study more complex systems.

States close to equilibrium were the first to be studied in thermodynamics. When slow changes were studied, the systems are still considered to be at equilibrium. In this regard, 'thermodynamics' is a misleading term because in thermodynamics the dynamics, the rate of heat and mechanical energy transfer in time are not taken into account.

Experiments show that at certain temperatures most substances undergo phase transitions. For example, water freezes at 0 °C and boils at 100 °C. Ice, as it melts, loses its crystalline order, which is clearly seen in snowflakes. At its boiling point, water evaporates and turns into steam, its gaseous state — a weakly interacting phase. The rate of change is absent from a thermodynamic description of these transitions because the changes occur, in relative terms, so slowly that thermodynamically the system is in equilibrium at any given moment. In boiling water, the time it takes for heat to pass into the volume of water is much longer than the time needed for exchanges of energy between water molecules. The macroscopic time for heat transfer is orders of magnitude longer than the microscopic time scale of molecular motion.

The next step in developing the concept of a thermodynamic system was made in kinetics. In kinetics, the interactions and composition within a system that lead to new compounds are studied. Chemical reactions were seen initially as direct interactions between reacting molecules. The combustion of hydrogen, which produces water, was described by the binding of two hydrogen atoms with one oxygen atom:

$$2H + O \rightarrow H_2O$$

As a balance of entities, this is a gross simplification of a much more complicated sequence of events. Meticulous studies of the oxidation of hydrogen, on which literally hundreds of papers and many volumes have been written, have shown that the process involves at least 30 different stages [155]. Even for a common reaction like this, its complexity makes it difficult to construct a complete model that includes every intermediate stage. Nevertheless, a simplified description, within limits, provides a useful picture of what occurs and serves as a phenomenological description of this bimolecular reaction. In chemical kinetics, as in thermodynamics, mechanical motion usually is ignored because of the assumption that all the processes and changes are slow.

Most practical developments were made before the general theory in thermodynamics was articulated. Steam engines were invented well before the principles of thermodynamics were discovered. Powerful chemical explosives were developed before the principles governing them were unravelled. Only in the case of nuclear explosions were the theories and practical applications developed simultaneously. When nuclear weapons were being invented there was an advanced fundamental understanding of chemical explosions, which provided insight and analogies for nuclear explosions. The concept of a chain reaction provided a common mechanism for understanding these violent, inherently non-linear and irreversible phenomena.

When the reaction zone propagates as a discontinuity in space and time, the state of the explosive abruptly changes in a shock wave. This concept of a rapidly moving discontinuity led to an in-depth understanding of the dynamics of these processes in many-particle systems where the shock wave propagates in a medium that is continuous, but the structure of the discontinuity is determined by molecular processes. Now the subsequent application of these ideas and mathematical theories has become helpful in studies of the demographic transition. The difference is in the substance and the scale of time, but the processes are basically of the same nature. If in the explosive shock wave it takes microseconds or less for the reaction to take place, then in the discontinuity of the demographic transition the changes take some 50 years and are determined by the human life time scale, which is the microscopic characteristic of the event.

Work on nuclear weapons in the Soviet Union and the United States stimulated non-linear studies. A legacy of the huge effort in military-oriented research is that mathematical methods and basic physical understanding have led to non-linear studies in other sciences. In the US, the Santa Fe Institute, a branch of the Los Alamos Laboratory, was created for research in this field. In Russia. the Keldysh Institute for Applied Mathematics became a well-known centre for non-linear studies and synergetics.

The field of non-linear studies also developed as part of theoretical physics and is largely based on the Ginsburg-Landau theory of phase transitions [154]. Belgian physicist Ilia Prigogine's discovery of dissipative structures and research on the evolution and self-organization of open systems were important advances in this field [138,144,145]. German scientist Haken developed this subject and coined the term 'synergetics' to describe the science of growth and evolution of open systems [143]. As the concept of complexity was introduced, methods of synergetics expanded into complexity studies in economics, social sciences and neuroscience. These advances led to an understanding of systemic behavior in very general terms and now these methods can be used to describe the global population system as an evolving system, discuss its stability and self-organisation.

2.2. Stability and Self-Organization in Systems

Initially thermodynamics was an intellectual model for economics and demography. In economics and demography, systems are treated as if they are at equilibrium because changes are regarded as being slow. For example, during regular growth in demographic models, the balance between births and deaths is considered small in comparison to the birth and death rates. Similarly, in economic models, the rates of economic growth are also considered small in relation to what occurs inside an economic system. Economic theory is also dominated by the idea of reversible exchanges in a market, which lead to equilibrium and slow, adiabatic, growth. Current economic problems like the dearth of long-term investments and the inequities in the distribution of wealth are so pronounced because modern economies are rapidly evolving systems and, consequently, far from equilibrium, changes are irreversible and inherently unstable, as seen by the fluctuations. The global demographic system, as it approaches the transition, is also no longer in relative equilibrium. Therefore, to study these systems as non-equilibrium systems, a radical new mindset is required. Rather than extending thermodynamic models beyond their limits, non-linear mechanics and a new systemic intuition should be used. These methods address rapidly changing systems far from equilibrium and can be applied in different fields of study that take self-organization into account.

In thermodynamics, the perfect symmetry of crystals was considered the only manifestation of a high degree of self-organization of matter into static and stable structures of interacting atomic or molecular particles. Now self-organization is widely recognized in evolving dynamic systems. As a fundamental property of open systems, it is observed on the scale of galaxies and the atmosphere as well as in other complex systems of different size and structure in a great variety of biological and social systems [146].

Transformations in the evolution of an open system over time and phase transitions observed in an isolated, closed system as its temperature is slowly changed are similar. Ice, water and steam are phase transitions observed when water is heated when energy is introduced. In open systems, transitions are associated with changes in the systems' complexity as the system develops in time. In complex systems, instabilities are the primary causes of internal changes that are intimately involved in the processes of self-organization, which is limited by internal processes.

Transitions in open and evolving system generally occur when two main and opposing factors, both changing in time, balance out. When this happens, a third force may determine the way the system develops. For example, if two opposing political parties receive the same number of votes in an election, as it happens in the age of sophisticated electioneering, a smaller third party or charismatic leader could suddenly and randomly decide the outcome.

This is a typical example of how an unstable equilibrium in an evolving complex system is resolved by a *bifurcation.* At a point when two identical paths may be taken, a fluctuation (the game of chance with all due uncertainty) may set things in motion in one direction or the other. Growth in the human population system based on this bifurcation scenario demonstrates how local instabilities can be resolved and finally lead to the overall stable development of the global population system [156]. Therefore, the random and chaotic instabilities of history can lead to a deterministic and predictable pattern of global growth. In this case, the non-linear mechanics of evolving self-organizing systems becomes an effective metaphor to interpret global history.

A mathematical analytic approach can be used to study human history because the scale for significant historical changes is much larger than that of local and temporal events. Braudel notes:

> Historians have over the years grown accustomed to describing this contradiction in terms of *structure* and *conjunction,* the former denoting long-term, the latter short-term realities [89].

This basic difference in *scaling* must be accounted for at every stage of growth, taking into account the changing time scale as the result of the dynamical self-similarity of global population growth. For example, at the beginning of humanity in the Lower Paleolithic, the interval for substantial change was roughly a million years, during the Middle Ages the period of change was a thousand years and currently the period of change is only 45 years. It cannot become any shorter, as it is limited by the effective human life span. This compression of time is a significant feature of the human story and a fundamental result of the theory of the growth and development of mankind. Although the transformation of the time of social development has been recognized by historians and anthropologists, it has not been studied in connection with the rate of population growth. This will be discussed in detail as a non-linear phenomenon in Chapter 5.

2.3. The World of Non-Linear Systems

Ideas about non-linearity and complexity come from mechanics and physics, and are foreign to the humanities and social scientists. Nevertheless, the insight that these concepts provide can and should be used to help interpret social phenomena and the evolution of the population system. Apart from providing the description of these phenomena in mathematical and quantitative terms, modeling can also provide images and metaphors that help to interpret social processes when a quantitative formalization is not really possible.

In most cases, if changes are linear, they are small if compared to a basic parameter of the system. For example, if the change in the deflection of a spring is significantly less than its size, these slight deformations are proportional to the force applied (Fig. 2.1). The force is the cause of the spring's deformation and the spring, as a mechanical system, is said to be linear. This implies a direct cause and effect connection between the force and the deformation. Only when the deformation becomes larger and exceeds the limit of the spring's elasticity and strength, do the effects of the force become non-linear. A large deformation of this rather simple system could break or permanently deform the spring. This shows how complex, unpredictable and irreversible non-linear changes can be. In these cases, the ideas of interpreting changes in terms of cause and effect are often useless, can be out of place or are simply wrong in complex systems making them difficult to control and change their pattern of behavior. A crude and paradoxical example in demography is that direct subsidies to families do not always result in an increase in the birth rate.

As long as changes do not exceed the linear limit, they follow a similar pattern. A spring will change in the same way as long as its elastic limit is not reached: regardless of if it is bent by 1 or 10 millimeters. Up to a point, changes in scale are *self-similar*. In this case, the relative changes of linear deformations cannot be compared because linear deformations have no inherent size of force or deformation. The lack of a scale for linear deformations, as far they have a general property of *scaling*, is a characteristic of linear systems.

A spring is a static system if vibrations are ignored. A simple example of a dynamic system is a pendulum. Since Galileo, it has been known that the length of the pendulum, not the amplitude of the swings, determines a pendulum's period. For small swings, the pendulum is a linear dynamic system and the static deflection of a pendulum is proportional to the force applied. This is the principle used in scales and weighing machines.

A pendulum, hanging down, is an example of a stable system. If disturbed or moved from its initial state of equilibrium, the pendulum returns and, if there is some friction in the system, the oscillations are dampened out. If inverted, the pendulum becomes unstable. An inverted pendulum could be at an unstable equilibrium within narrow limits, but even a slight disturbance will bring it out of this uneasy balance. The pendulum will accelerate and swing down, passing from an unstable to a stable position. This transition is non-linear because in most cases the pendulum's fall is independent of the disturbance that initially upsets the unstable system. Even in this simple model the linear connection between cause and effect is lost.

The stability of systems largely depends on internal degrees of freedom. If the pendulum's support oscillates rapidly enough, the vibrations will stabilize the unstable inverted pendulum. Another example of how internal motions can change the stability of a dynamic system is a spinning top that is stabilized by the gyroscopic forces from the top's rapid rotation. The general theoretical treatment of stability of complex systems was developed in synergetics, when the interaction — the synergism — of different factors was taken into account.

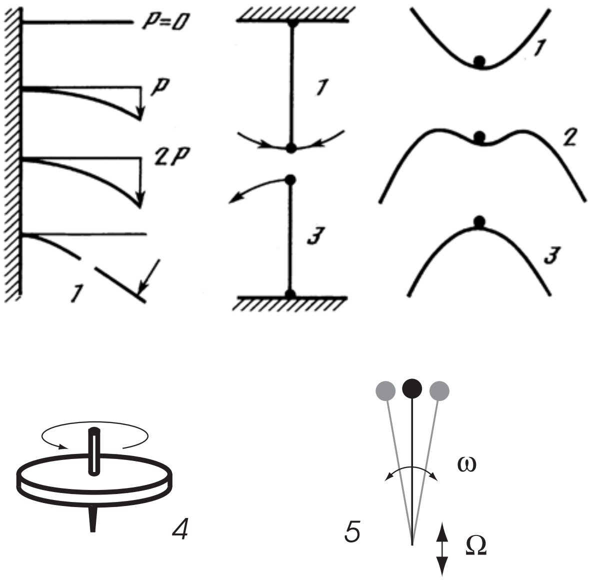


Figure 2.1. Stability of systems

Linear (1) and stable systems (2), systems with limited stability and unstable systems (3), a spinning top (4) and a pendulum with an oscillating suspention (5) when W >> w becomes stable

Feedback can change the behavior of a complex system. Negative feedback stabilizes a complex system and causes the system's changes to become more linear. Positive feedback destabilizes a dynamic system. These instabilities can finally cause oscillations and non-linear boom and bust cycles. Complex systems can be controlled by adjusting the feedback. For example, adjustments of tax and interest rates change the feedback in an economic system and have a significant effect on its growth and stability. In this case, the Central bank is the controlling factor in a complex, inherently unstable dynamic system of a market economy. In the case of population, demographic policies may directly increase or decrease birth rates. For example the education of women, an indirect information and cultural factor, decreases the birth rate in a society and shows the complexity of the population system's behavior.

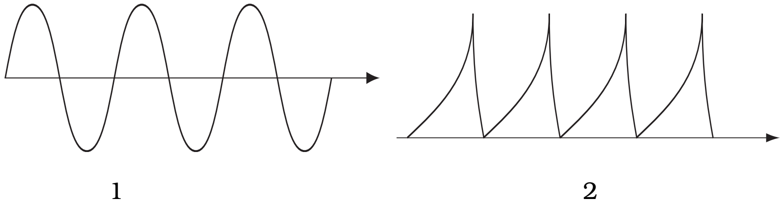


Figure 2.2. Oscillatory behavior of a system

Harmonic oscillations (1) in a stable linear system and the boom and bust cycle in a non-linear system with limited stability (2)

Human beings generally have a linear outlook on the world. Most events are viewed as a continuation or the direct result of an earlier event, linearly coupled to the past. This linear vision of the world is based on the concept of inertia, on the 'business as usual' pattern of behavior. While the linear model is a powerful way of assessing expected changes, there are limits to projections made by a direct extrapolation into the future. A linear model works well as a straightforward extrapolation of the present for as diverse cases as the path of an animal being chased in a hunt, to a man driving a car, and to the weather forecast for tomorrow. In each case there are limits to these projections: the beast may unexpectedly leap, the car can skid and the driver loses control, and the weather can change. The further one looks into the future, the greater is the difference between the expected and unexpected in a world of increasing complexity. As linear models are pushed further into the future, the difference between the expected and unexpected, of complexity and chaos increases, once the threshold of linear certainty is passed.

This pattern of instability can develop either on a small scale, as in the case of a person's actions or on a larger scale like Europe on the eve of World War I. At that time, Russia and Germany's populations were growing by 2% and their economies by 10% annually, however, economic disparities and social tensions were rapidly multiplying and armies and armaments were being built up. The system, the social and political system of European security, was approaching its limit of stability. The rate of these immense changes was a signal of the impending crisis and the slow adjustments of the social and political infrastructure failed to meet the emerging tensions.

A small disturbance, the assassination of Archduke Ferdinand, kicked the system out of equilibrium and sent Europe, and ultimately the world, into the chaos of the world wars. Forty years later, after two world wars and the loss of 280 million people, the world finally returned to a state of relative equilibrium. Although this is a simplification of history, it is a fair description of events in terms of the dynamic stability of the global system.

In demography, most annual changes are small. At best, a population can grow by 4% a year and, as in some African countries, double in 17 years. Linear extrapolations and forecasts work because of the relatively small size of annual changes. For a period longer than one or two generations, numerous assumptions must be made in order for a linear model to work. Projections become more difficult as a system approaches or passes through a transition, an unexpected limit in its linear or self-similar development. These considerations must be kept in mind when constructing even the simplest and straightforward models of growth and stability in terms of systems dynamics and synergetics [143,152].

The demographic system can also be seen as an active or exited media, similar to chemical systems that exhibit periodic chemical reactions or explosions. Lasers are exited systems with an active media that discharge their energy into an organized beam of light. In fact the theory of lasers, developed by Haken, contributed to the study of the properties of complex systems and to the ideas of synergetics.

The concept of the self-organization of a system becomes important when changes expected in a complex system at thresholds and limits in development are encountered. The atmosphere is a good example of a complex and unstable open system. Heated by the Sun and interacting with the land and sea on a rotating Earth, the atmosphere exhibits many types and scales of self-organization that are best seen when viewed from above.

Cyclones, atmospheric fronts and thunderstorms are the result of self-organization in the atmosphere and clouds demonstrate a regular mapping of the spiral structure of cyclones. These phenomena are best seen from a satellite and are usually difficult to discern from the ground. Consequently, local weather is chaotic and difficult to predict, while long-term seasonal changes follow a more stable and regular pattern.

Atmospheric fronts, abrupt discontinuities that separate regions with different weather, are dynamically structures similar to the population transition in the growing and evolving global population system. The passage of an atmospheric front can change the low pressure, cloudy and unsettled weather in a cyclone to a high pressure anticyclone with stable and clear weather. A similar change is expected after the demographic transition. Human growth and development, which followed a small-scale irregular pattern of growth up to the demographic transition, may enter a relatively calm and more stabile mode after the transition. The turbulence and chaos in an atmospheric front are similar to the stress and strain and the loss of temporal and spatial coherence, which has become so conspicuous during the demographic revolution. If this analogy is an intellectual model of future developments, then we may expect, after the storm the transition to a more tranquil and less turbulent period in global history. Self-organization is a dominant feature in complex systems and the greater the complexity, the more varied it becomes.

Life is an ultimate example of self-organization in nature. The incredible variety of living creatures on Earth has evolved and changed over billions of years and human beings are the final outcome of this process. Self-organization and evolution is characterized by a lack of aim and goal. By the chance of mutations and necessity of selection, a sequence of seemingly random events leads to evolution and the appearance of highly organized creatures. That is why William Palely and Richard Dawkins used the metaphor of 'the blind watchmaker' to describe self-organization in nature and Adam Smith introduced the concept of the 'invisible hand' in market economics.

Anthropogenesis took 3 to 5 million years — a short time for the appearance of a new species. Then nature passed a threshold, for reasons poorly understood, a qualitative limit in evolution, which led to the appearance of human beings with a highly developed brain. The subsequent growth and development of mankind is a study of the self-organisation of our species, a singular and remarkable process in nature. Today, in a non-linear world of rapid and unpredictable changes, humanity is becoming increasingly unsettled as it approaches a historic limit in its development when it blows up in the ultimate instability of the population explosion.

2.4. Interactions in the Population System

The internal and external interactions occurring in a system is the best way to study its nature and development. Examples in physics or chemistry show how an understanding is reached by simplifying the model. In the following discussions of demographic processes, all descriptions will be phenomenological because the complexity of human society defies any attempt at a more elementary, reductionist treatment of growth and development. Even the processes of birth and death, as factors of growth from a fundamental point of view, are also a phenomenological, generalized description of these critical transitions in human life.

The global population will be seen as an open system that literally lives off the resources of the environment. In the first approximation, the limits of these resources — open access resources — will not be taken into account. This assumption simplifies the analysis and is in accordance with the trends of development of the population system in the past. Only at the next stage in the description of social evolution, can the population system's external interactions be taken into account and new 'limits to growth' are then to be found. Then the borders of the system could be enlarged to take into account interactions with resources.

Much, if not all, of what goes on inside a system can be described by interactions between the system's components. In the case of the global population system, the components are human beings, tribes and nations depending on the magnitude of the process considered. The interacting elements migrate and mix, co-operate and fight, and are responsible for everything that occurs inside the system. These interactions keep the system literally alive, active and developing. The impact and period of these interactions are different and their time scale is what matters in assessing their significance. Even in the distant past, when the global population was much smaller than today and the world was divided, populations of different regions slowly but surely interacted. Only then the time of these interactions was correspondingly longer. That is why the changing time scale of history is essential in comparing developments happening throughout our past.

Presently, these processes in the global population system are attributed to globalization. In the past and in terms of the systems dynamics, however, the global population system has always behaved as an entity. Today, during the demographic transition globalization is noticed mainly because the scale of time of the processes has become the same as the human life-span.

2.5. Mankind as a Social Species

Biologically all members of the global population system are the same species, *Homo sapiens,* and have the same number of chromosomes — 26, which is different from all other primates. All races can intermix and socially interact. Hence biologically, man is a distinct and comparatively uniform species, which belongs to the same genetic population system. Human beings inhabit practically the entire world, and have adapted to the most adverse conditions. Only the most extreme regions — the highest mountains, the far north and Antarctica — are uninhabited. The population distribution, however, is far from uniform, vast areas that are suitable for life are sparsely populated.

Human beings are special because, in terms of numbers, we are five orders of magnitude — a hundred thousand times — more numerous than any mammal of comparable size and position in the food chain. Only domesticated animals that live with

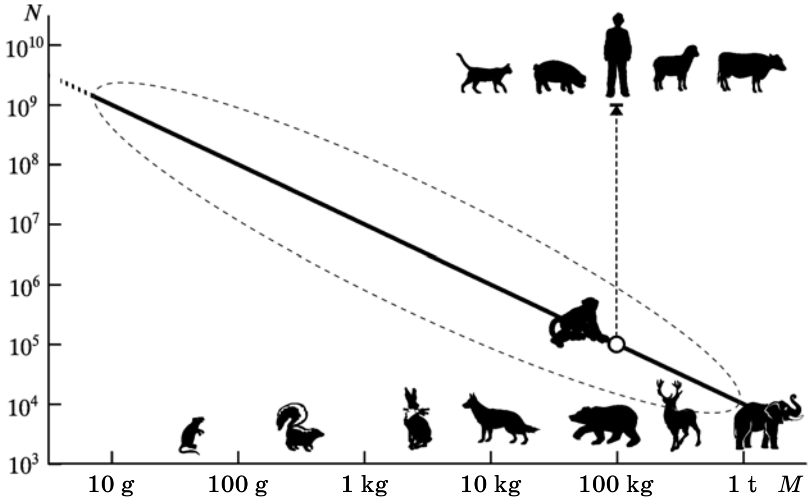


Figure 2.3. Numbers of a genera depending on body weight

and around humans are not naturally limited in their numbers in the same way as other creatures are in the wild. For example, the two billion cattle in the world eat more food than all people do. If humans were like other animals and members of the ecology system, then the human population would be in the hundreds of thousands and man would inhabit a limited territory, an ecological niche like all other creatures.

The appearance of man caused a qualitative change in nature. This change occurred because of the human brain and now man's highly developed intelligence, consciousness and cooperation differentiate humans from all other animals and give him a remarkable advantage in multiplying his numbers — the primary aim of any species. But to attain this, an extended amount of time is needed to develop the mind. The human brain increases in size by four times since birth — more than any other animal. Mammals of a similar size, physiology and diet like cats, dogs and — I am sorry to say pigs — all reach a reproductive age in 2 or 3 years. In human evolution, the reproductive capacity of a single being is sacrificed to program the brain and develop intelligence, which led to a new pattern in man's reproductive behavior. Now it takes at least 20 to 30 years to train and educate a young member of soci-

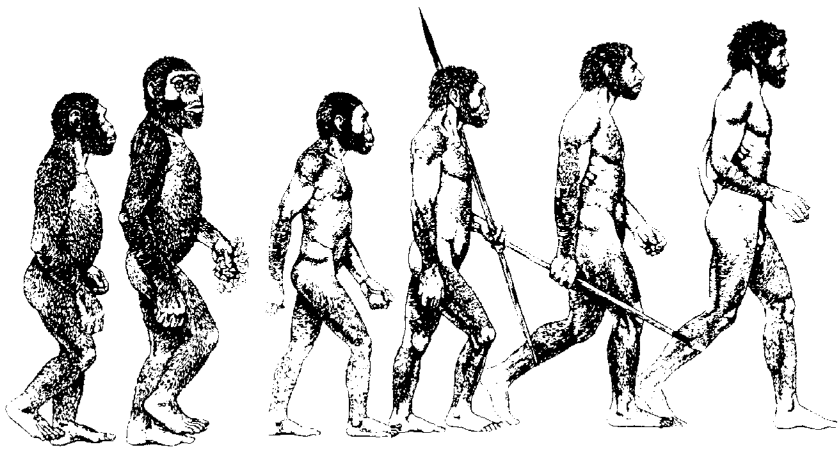


Figure 2.4. Stages of anthropogenesis [29, 42]

The development of human beings began some 4–5 million years ago and initially was connected with bipedal locomotion (1). The next stage 2–1.5 million years ago the *Homo habilis*, the tool making man appeared (2). Later 100 000 years ago the pithacantropus arrived, with a stronger build (3). Next came *Homo sapiens* and some 40 000 years ago the Neandertalian man of a lesser size (4) very similar to the modern human (5) appeared.

ety. This interval will become a critical temporal parameter in assessing the present state of mankind.

From the Stone Age to the Neolithic, humans lived off nature as hunters and gatherers. In search of food and space, mankind spread throughout the world and has inhabited practically the entire planet since the early Paleolithic. Sustaining not only large numbers, but also a high multiplication rate, mankind at a certain stage of development, associated with the Neolithic revolution, did separate itself from most of nature. Since then humans began to create an environment, a habitat much of their own making.

Lotka [136] and Volterra [137] developed mathematical theories to describe animal communities. In these models each species' rate of multiplication was assumed to be proportional to its population size, and the interaction between species is described in terms of predator and prey. The linear dynamics of the systems' growth is exponential and limited by a logistic curve. Under certain conditions, oscillatory patterns develop, which have been observed as population waves in natural habitats supporting the models credibility.

But these models are not applicable to human populations because the circumstances of man's growth and development are quite different. Humans are a single species that grows independently in an open system according to an interactive mode of development. Mankind's growth is not exponential with a rate proportional to the first power of the population. Instead, mankind's growth rate is proportional to the *square* of the total number of people. Consequently, humans significantly outnumber all other comparable animals and the human population is only limited by man's inherent propensity to multiply.

As far as all humans are biologically similar, there are recognizable and well-defined socially relevant differences. In order to place these differences in the context of a single global system, the period of their existence, rate of change and the size of the group must be taken into account. The time it takes to build up an ethnic group and identify a dialect is less than the time it takes for a nation or language to emerge. The separation and formation of races takes even longer. All these processes are the result of self-organization depending on cultural and information based factors.

2.6. Components of Growth

The main equation in demography is the obvious way to determine the factors of growth. For any country or region at any moment of time growth may be represented as:

$$\text{Growth rate} = \text{Births} - \text{Deaths} \pm \text{Migration}$$

The rates are usually reckoned in annual percentages or in numbers per thousand per year. For example, in 18th century France the birth rate was 4.5%, and the death rate was 4% (Fig 2.5). Therefore, the annual growth rate was 0.5%, an order of magnitude less than the birth and death rates. Although these data are averaged over a decade, large fluctuations are present. If

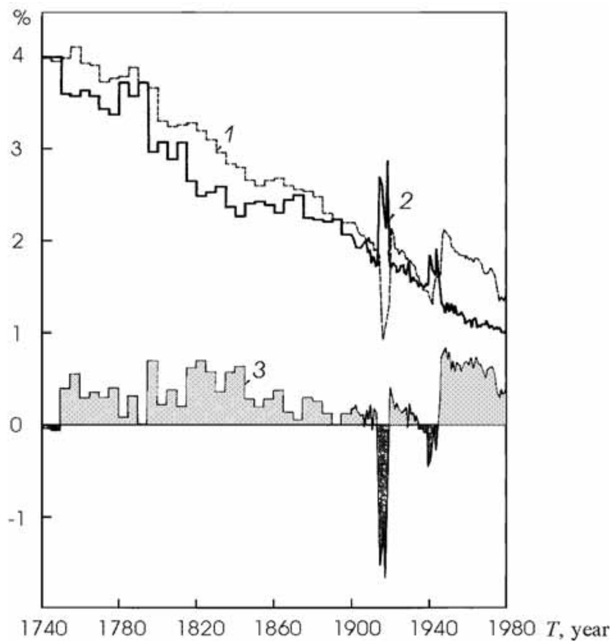


Figure 2.5. The dynamics of the population of France 1740–1980

1 — birth rate, 2 — death rate, 3 — population growth, % per year, averaged over a decade [64]. Note baby-boom after 1945

these trends are extrapolated into the past, the birth and death rates increase and the net growth decreases. As the present is approached, both the birth and the growth rate decrease and, paradoxically, growth increases until the transition. After reaching its maximum, the growth rate rapidly decreases and the birth and death rates gradually — asymptotically — approaches the same limit as the population stabilizes.

In France, where this transition was first recognized, it all took nearly 160 years for the population first to stabilize and then decrease. On a global scale, the demographic transition is much more rapid. In fact, it is occurring as fast as possible in two or three generations. For a stabilized population with a constant population and age structure, the birth rate has to be equal to the death rate if, as is the case for the global population, there is no migration. When these two trends — before and after the transition — are compared,

Table 2.1. Matrix of assumed high values of annual net migration flows, (in thousands)

From \ To	North America	West Asia	Japan Australia	Western Europe	Eastern Europe	All
North Africa	90	15	20	275	75	475
Sub-Saharan Africa	115	5	40	275	75	510
Central America	550	0	10	45	45	650
South America	150	5	15	45	45	260
West Asia	25	0	10	10	20	65
South Asia	300	15	80	150	290	835
China	220	0	40	50	160	470
South East Asia	550	10	135	150	290	1135
Total	2000	50	350	1000	1000	**4400**

it is clear that the growth follows its own pattern of long-term changes. Growth rate may be seen as the difference in the birth and death rate, but the resulting growth rate is the significant number. Thus growth is determined by the social capacity to multiply and not only by the birth rate. In a separate country or region with a decreasing total fertility rate (TFR) for a society migration becomes a significant contributor to the balance of the growth rate.

In the world the total migration flow of 4.4 million is less than 0.1% of the global population and is 1/20 of the number of people added to the world each year. The number of transnational illegal migrants can be much larger and according to some estimates, it may reach 20 million a year. The flux of migrants inside countries is even greater, and in China numbers as high as 200 million are quoted. These figures indicate increased mobility in the modern world. If all migrations throughout the world, as it has been mentioned, are summed up it is obvious that in a global balance, they cancel out. This considerably simplifies matters in analyzing global growth as far as the human population is confined to planet Earth [52].

Chapter 3

Modeling Global Population Growth

> The sciences do not try to explain, they hardly even try to interpret, they mainly make models. By a model is meant a mathematical construct which... describes observed phenomena.
> The justification of such a mathematical construct is solely and precisely that it is expected to work.
>
> ***John von Neumann***

3.1. Principles of Modeling

To construct a model for global population growth, the methods developed to study complex dynamic systems must be applied to population data supplied by demography and anthropology. While fitting a curve to the numbers and extrapolating an expression to describe the available empirical data could be the first step in building a model, the main objective is to present the development of humanity in terms of functions of time. The purpose of the model is to gain an understanding of the process of growth and not simply to present the observed numbers as an empirical formula that only describes the data.

The data are primarily historical dates and the results of censuses. These numbers and facts are unfamiliar to physicists, and one of the purposes of this study is to introduce physicists and mathematicians to a new set of problems. At the same time, examples from physics, which are just as unfamiliar to demographers, economists and historians as the data from demography is to physicists, will be used. In this case, the process of reconciling data and applying mathematics is best developed in mathematical modeling and theoretical physics. In some cases, it will be possible to identify concepts and recognize well-known ideas in this new setting in social studies. Then the model will lead to a new way of describing events, to greater insight into the nature of the phenomena and, finally, to a theory of growth.

The data and the model are but crude images of the real world. All models only provide an approximate description of complex events because they take into account a limited number of factors. Indeed, for a system as complicated as the population of the world, the complexity of events provides the opportunity to attain an overall description of what is happening in the system by a statistical treatment of the data. This approach is feasible because most of the multitude of relevant factors, different interactions occurring simultaneously, with spatial and temporal variations that are summed up when the average numbers are used. This is achieved, as Mihaljo Mesarovich has suggested, in the **d**ominant **r**elations **m**odel. The DRM principle is the art of building models by choosing the appropriate dynamic variables.

The DRM approach was formalized in synergetics, where asymptotic methods for singling out significant variables were developed. In the case of the global population system, the operational number is the global population. When compared to the total number of people in the world, the regional distribution of the population in towns and villages, distributions by age and income are of secondary importance and most temporal variations and spatial distributions can be ignored when describing the overall features of growth and development of the global population — this is the meaning of the statistical approach. While this may seem like an oversimplification, it is justified both by the results obtained and an in-depth analysis of the validity of an asymptotic, long-term approach.

3.2. Linear and Exponential Growth

Before developing a non-linear model for the growth of mankind, the more familiar cases of linear and exponential growth should be considered. The global population passed 6 billion in 1999 and is growing by approximately 80–87 million persons per year. By extrapolating this growth rate into the past, then 70 years ago, when I was born, humanity could have begun from point zero. Thus, linear extrapolation is currently meaningless because the population growth rate has drastically changed during the human lifespan. The same thing can happen with any long-term linear projections into the future. Thus, linear models and extrapolations have a very limited range, especially during a critical time of rapid change.

Exponential growth models are also only locally adequate and can be used only if growth is really following this pattern. Assume, for example, that the population in the past doubled every 40 years. By expressing the global population as a power of 2: $6 \cdot 10^9 \sim 2^{32}$, then 32 doubling times or 1280 years ago Adam and Eve would have lived in the 7th century. Even if the doubling time is increased to a Methusilian 400 years, the beginning of mankind would be in the Neolithic, when the population was already 10–15 million people. Therefore, an exponential growth curve has a very limited range (Fig. 3.1). In other words, linear and exponential growth is only valid over a short period of time and these laws of growth only show the instantaneous rate of change and, in the case of global population growth, they cannot be expected to represent long-term changes.

Linear and exponential growth, which are often used in modeling, are described by linear equations and do not depend on the absolute size of the population. Exponential growth implies that there is an intrinsic time of change, the doubling time. In mathematics, change in steps of $e=2.72$ is commonly used, while the doubling time T_2 is 30% less than the exponential time of growth $T_2=0.7T_e$.

Linear growth scales because it does not have an intrinsic time of change. This is a significant feature of a dynamic system and means that the process is independent of the scale of a certain variable. Scaling also indicates that the functions describing growth are power functions. Exponential growth and the logistic curve (combined by two exponents) do not scale because these functions are transcendental.

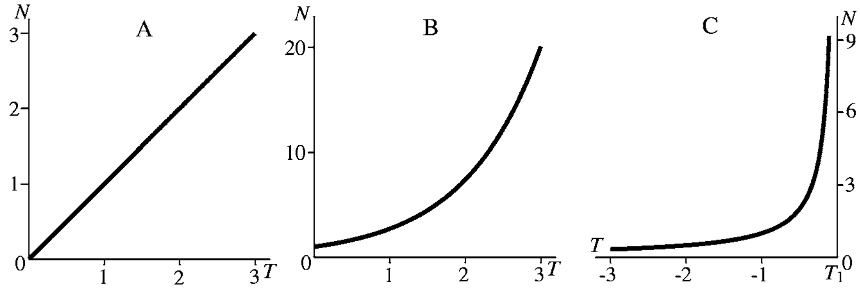


Figure 3.1. Linear (A), exponential (B) and hyperbolic (C) growth

The logistic (Fig. A5), since it was introduced by Belgian mathematician Verhulst in 1838, has been widely used to fit growth curves and describe the passage of the population from one level to another. If exponential growth has only one asymptote, which is in the past, logistic growth has two asymptotes. One is an exponent in the past and the other, which describes the approach to the upper limit, is in the future. Unfortunately, in population modeling asymptotic behavior is usually not taken into account. The asymptotes describe the long-term changes in population before and after the transition and they depend on the intrinsic process of growth, rather than the transients in passing from one level of population to another [76].

Hyperbolic growth has a rate of change proportional to the second power of the population. After a slow start, it gradually grows and eventually becomes faster than exponential growth when it goes to infinity in a finite time. Hyperbolic growth has two asymptotes (Fig. 3.1C). The first asymptote describes the past. As time goes back to infinity, the population gets smaller and smaller, ever more slowly approaching the base line of the graph. No matter how far back in history the model is taken, there are still some people around. The other asymptote occurs when population growth approaches the critical date when the curve describing growth blows up and goes off to infinity, never crossing the critical date line. These differences in the long-term asymptotic patterns of behavior are essential features of global population growth. The asymptotics show the nature of the

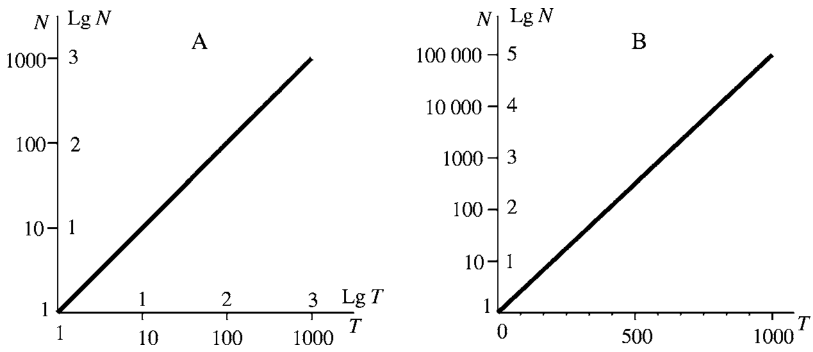


Figure 3.2. Linear growth on a log–log plot (A) and exponential growth (B)

On the semi-logarithmic plot B all exponents appear as a straight line

change over the long-term pattern of sustained growth and a meaningful analysis of population growth should take this into account. Despite their simplicity, asymptotics provide a clue to unraveling and depicting the physical laws determining the growth of a developing system. Hyperbolic growth describes most of the development of the population system remarkably well and the current asymptotic trend corresponds to the blow-up stage of the global population explosion.

It is instructive to first apply this reasoning to systems that are easier to interpret than demographic systems. For example, the output of a car factory, under constant conditions, will double if time is doubled. Also, two factories will produce twice as many cars in the same period: the output is a linear function of time and the number of factories. But if two or more factories co-operate, their joint output may be larger than the mere sum of their product. Thus, in a system of factories, production may grow non-linearly with the number of interacting plants. This is the main reason for co-operation and mergers in industry.

In the case of human beings, growth can be even faster than linear and follow an exponential law of compound growth because once people are born they can then multiply on their own. Exponential growth is linear and additive. If the number of people is doubled, the number of offspring will also double. The doubling of the population will happen over an interval equal to the intrinsic doubling time. Exponential growth depends only on the individual capacity of the human being, or rather the family, to multiply and does not explicitly depend on interactions in a demographic system.

Malthus made the next step in describing population growth. He noticed that in America, which had unlimited space and resources, the population of European settlers doubled in 25 years [48]. He then tried to take into account the interactions of food and growth in the population system by assuming that food production would grow linearly and be slower than the growth of the population. This was an important conceptual step forward, as he argued that the slower rate of food production and the resulting hunger would determine the growth rate and cut off exponential population growth.

A fascinating essay about the legacy of Malthus and his contemporaries, Godwin and Condorcet, as moral philosophers was written by John Avery [35]. In *Population, Economic Development, and the Environment*, an international group of economists and demographers discuss the Malthusian conflict, factors underlying fertility changes and strategic development issues related to the population [73]. These ideas were popular in the 19th century and still have many subscribers, including the authors of the first reports on global modeling to the Club of Rome.

But regardless of how detailed the data are, the influence of all factors of growth — production of food, energy, raw materials and industrial development — on the growth rate cannot be properly accounted for in the reductionist framework of global modeling. There was no proof that the system was complete and took into account all the necessary factors to provide a representative model valid for a sufficiently long period. Next, there was no explicit connection between development and population growth. On the other hand, these global models were hardly ever tested by working out past growth and development. Of less practical value, this could give some insight into the validity of these global models. The most important and widely recognized outcome of this work was the general recognition of the fundamental significance of global problems.

These attempts to model growth and development do not really take into account that the global population system is extremely complex and has many different degrees of freedom. The fallacy of detailed global population modeling is that no matter how compleat the database is the model still does not provide an overall description of global population growth because it is based on local and temporal data. An effective method to deal with the complexity in global modeling requires a new approach and a basic change in one's attitude and mindset.

Unfortunately, in demography the global population has never been viewed as a single dynamic system, because in this case it seemed impossible to identify the social and economic factors for growth that is the main goal in interpreting demographic data. But only by abandoning the reductionist approach of demography (and economics) and the adoption of phenomenological methods it is possible to understand and interpret global population growth over its entire course of the development of humanity.

Paradoxically, growth can be effectively described phenomenologically as the result of all complex interactions that will ultimately determine growth without going through a detailed summation of the factors of growth. The experience of describing complex systems shows how promising such a generalized asymptotic treatment can be. This approach allows the growth and development of the human system to be described and interpreted in quantitative terms when the global population is seen as a dynamic system with interactions spanning the world throughout all history.

In this case the number of people engaged in development is the sum of all: a millionaire and a homeless bum have the same input in the total population, although their contribution to development is different. By applying the same value to everyone in this interactive system, growth is determined by everything that occurs in the system, and, in one way or another, involves everyone. Then the processes that occur in society are seen as the average result of the interactions which determine growth. If the nature of this type of collective development remains the same, the dynamics of growth can be expected to remain the same and be dynamically similar as long as the pattern of growth is valid. It can then be assumed that these processes of growth are self-similar: the ratio of relative changes in population and time are constant, and, as a necessary consequence, it scales and a power law will describe growth. These general properties of functions describing growth are essential for a description of the development of humanity. The first step is to identify the parameters of global population growth.

3.3. Hyperbolic Population Growth

Von Forster [50], von Horner [52[and Russian astrophysicist Josef Shklovskii [110] independently proposed a formula to describe world population N as it changes with time T:

$$N = \frac{C}{T_1 - T} = \frac{200}{2025 - T} \text{ billion} \qquad (3.1)$$

This simple expression fits the data for world population growth remarkably well over more than the thousands of years leading up to the population explosion (Fig. 1.2). The formula was suggested as an empirical expression and not given any greater meaning in demography, aside from the fact that it fits global demographic data. Nevertheless, it should not be seen as only an empirical expression, but as a physically meaningful law, which describes hyperbolic growth of the global population driven by a quadratic interaction. Seen as an asymptotic expression, it indicates that the process of growth scales. This led me to reappraise the hyperbolic blow-up formula and identify the self-similar growth of the global population.

At a glance, the equation seems limited in its validity in the past and the present. In the first place as year 2025 approaches the global population goes off to infinity. This has led some to believe that the world is heading for an impending crisis [50]. Next, the expression is not valid in the distant past because it indicates that 20 billion years ago people were already living (presumably some ten cosmologists, who observed and discussed the Big Bang). In other words the formula is limited in the past and present because of the asymptotic divergences of hyperbolic growth. This is exactly what should be expected because scaling power laws are only intermediately asymptotic: the asymptotic behavior is valid only at certain stages of growth.

Russian theorist Grigori Bahrenblatt recognised this in his classic studies of self-similarity [140,159]. Setting limits for hyperbolic growth as limits of scaling led to a simple and, in a sense, complete description of the growth and development of the human population system. If the ten cosmologists who presumably lived 20 billion years ago ever existed, their life span should have been a billion years, which is just as meaningless as the idea of their existence. The blow-up, as 2025 approaches, means that in 2024 the global population should double in less than a year — this is equally nonsensical.

To determine the limits of the asymptotics the human reproductive period and lifespan should be taken into account to determine the temporal extent of scaling. As the global population blows up its maximum rate of growth is effectively limited by the human life span. This is the meaning of the demographic transition when every country will pass through a demographic transition in which the growth rate reaches its maximum and then rapidly declines. This was first observed in developed countries (Fig. 3.4) and now the global demographic transition is seen worldwide (Figs. 5.7 and A2).

At the other extreme, at the very beginning of human development, it can be assumed that the growth rate is also limited. A general requirement for the continuity of growth of a population is that growth cannot be less than one person per generation. Although this is a very crude description of the early stages of growth, it provides the necessary minimum growth rate and effectively limits the asymptotics in the past. Therefore, two cut-offs have to be introduced: one at the population explosion and the other at the beginning of humanity.

The methods to introduce a cut-off were developed in theoretical physics. For example, the divergence of the electric field of a point charge can be cut-off by bringing in an effective radius for the charged particle. Mathematicians often challenge the logical consistency of this *ad hoc* procedure, but physicists know that it works well. By introducing a cut-off with a time constant of 45 years, the singu-

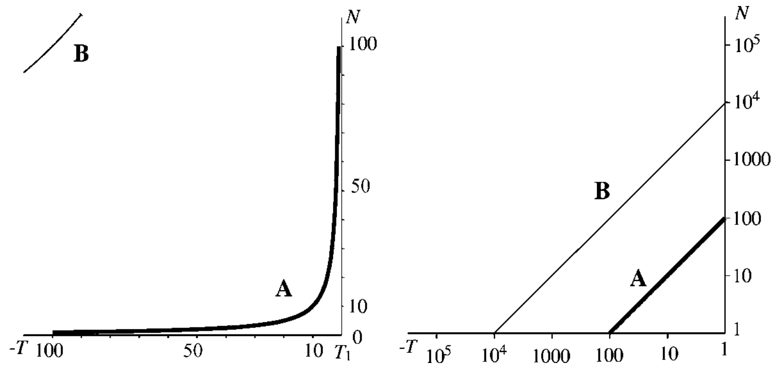


Figure 3.3. Hyperbolic growth on a linear and double logarithmic chart

$$A - N = \frac{100}{T_1 - T} \qquad B - N = \frac{10000}{T_1 - T}$$

T_1 is the singularity at which the population blows up to infinity.

larities in the past and the present are eliminated and the growth rates for the initial and last stages of growth are regularised. By bringing a specific time t= 45 years into the model, as the microscopic parameter of the phenomenology, the expressions for the growth rate are transformed in the past and extended into the future, beyond the divergence in 2025. The appropriate expressions exclude the singularities, have the required asymptotics and describe human population growth throughout history and extrapolate it into the future, past the singularity at 2025. In fact, when this is done, the critical date shifts to 2000. It should be noted that the time constant, which was deduced by fitting population data during the global transition to the model, is the same for the past and present.

This model has developed into a self-consistent theory that describes humanity from its origins up to the demographic transition and beyond, where, according to the model, the global population will eventually stabilize. Although the theory uses the bare minimum number of constants, it can account for and be used to interpret data from anthropology and history, economics and demography. While the initial calculations, to be found in the Appendix, are elementary, developing this theory further requires more advanced methods of non-linear mechanics.

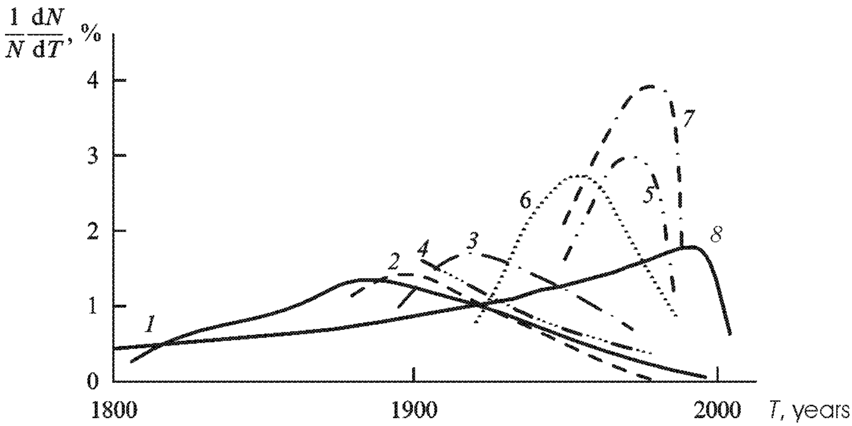


Figure 3.4. Relative growth rate during the demographic transition for:

1 — Sweden, 2 — Germany, 3 — USSR (Russia), 4 — USA, 5 — Mauritius, 6 — Sri Lanka, 7 — Costa Rica, 8 — Model. The data is smoothed, so as to show the general trends. Compare with Fig. 2.5

3.4. The Law of Quadratic Growth

Hyperbolic growth is driven by a rate of growth proportional to the square of the population. In formal terms, this is only a step away from exponential growth, which is simply proportional to the population. But changing the power law leads to a profound change in the nature of the process of growth and development. To gain insight into the mechanism of hyperbolic growth, it is best to consider the primary expression for the rate of growth:

$$\frac{\mathrm{D}N}{\mathrm{D}t} = \frac{N^2}{K^2} \tag{3.2}$$

where $K = \sqrt{C/\mathrm{t}} = 62\,000$ is the main dimensionless parameter that determines the rate of growth for a collective binary interaction in a generation and time $t = T/\mathrm{t}$ is expressed in units of 45 years.

This basic expression equates the rate of growth with development. The term for development states that growth depends on the total population N. It is a function, the square, of the number of people and expresses the state of the global population. This expression may be interpreted in a number of ways.

First, N^2 is the network value as a measure of the complexity of the population and equal to the number of connections between N people. Next, this function can be interpreted as an effective field, a concept generally used to describe collective phenomena in many-particle physics. For example, this interpretation appears when interactions in magnetic substances or plasmas are described. An instructive case is provided by the theory of non-ideal gases, where the Van-der-Waals interaction is an analogue of the collective interaction driving mankind. In terms of econometrics, the phenomenological interaction is the production function in a meta-economic model that describes the development of all humanity.

The growth rate for the population system should be seen as the co-operative result of all partial processes that contribute to development. The growth rate is the interactive outcome of all inputs of industrial, economic, cultural, social, biological nature in the network where its complexity is a function of the global population. The human capacity to multiply, which taken alone would lead to exponential growth, is only one of the mechanisms that contributes to and determines growth in this complex non-linear system. Reducing the growth law into different channels, which add up linearly, contradicts the essentially non-linear nature of the process. Therefore, it is impossible to break up the dependence of growth into a sum of different factors. The quadratic law is the interactive and collective mechanism of growth, where the factor K normalises its value in terms of effective growth. Parameters K and $\tau$are the only constants that describe the total history of mankind and the appropriate formula express all pertinent numbers. They describe the growth of humanity in remarkable detail where no evolution is assumed to adjust their values to changing circumstances since half a million years ago.

After an immense population increase, the self-accelerating quadratic growth rate reaches its limit and culminates in the breakdown of scaling at the demographic transition. At this point, growth is limited kinematically by the internal nature of the growth process and not by a lack of external resources as it is assumed in logistic growth. The discussion of the systemic nature of development will be covered in Chapter 6.

3.5. The Informational Nature of Growth

After the formal phenomenological description of the interaction is established, the next step is to interpret it through an approach, which could connect the general description with human activities. This is needed because the interaction, particular to humans, involves an internal mechanism for a non-linear multiplication of the factors of growth, which leads to the remarkable blow-up of human numbers, rather than their linear addition.

The quadratic law can be interpreted in terms of the transfer of information and communication as the basis of a collective interaction. The distribution and transfer of information (knowledge, technology, customs, crafts, art, religion, science, etc.) from generation to generation is a particular aspect of humans and what makes humans fundamentally different from all animals. The process of information propagation and exchange is both co-operative and multiplicative as information spreads in space and spans time. It may be conjectured that this generalised information transfer moderates development and determines the growth of mankind.

Humans, unlike other animals, have a long childhood during which they are brought up and this process of education now takes 20 to 30 years. In these decisive formative years, information is transmitted vertically between generations, establishing powerful links with the past and contemporaries. These links are deeply entrenched in the personality of each member of society in its character and consciousness.

Information is also transferred horizontally, in the space of informational interaction. These connections unite people, organise co-operation and set up common patterns of action. In this context, information should be seen in general terms because it unites people and, in many ways, leads to constructive and destructive interactions. Because this is a phenomenological concept taken from physics, this information-moderated interaction can be seen as an entity that expresses the organisation of society. It may be further conjectured that this agent, affecting everyone, is associated with consciousness.

The collective state of mind is the basis for development and depends on the informational interaction of everyone. Mathematically, it is proportional to the square of the population, which is a measure of all binary connections. This relationship exists because the propagation of information is multiplied by an extended chain reaction as the main process for propagating information. The exchange of information is fundamentally different from an exchange of goods and services because for goods and commodities, the total number of objects is conserved and the objects are only redistributed by the market. In an exchange of ideas, news or information entities are not exchanged, but are propagated as the number of entities is irreversibly multiplied.

Currently the informational character of the modern world is referred to as an information network society and Manuel Castells has produced an extensive and in-depth study of this in *The Rise of the Network Society*, as the first volume of *The Information Age: Economy, Society and Culture* [102]. Its inspired *Prologue* has much in common with this book in describing the present state of humanity that always has been information-moderated. From the first steps of *Homo* and the development of speech and language, humanity began developing as an information society. The Internet and multimedia are only the most recent manifestations of the information society.

The only factor that has changed has been the rate of growth, which started at a very slow rate and has accelerated ever since. If humanity had not developed as an information-moderated society, it would be impossible to explain the origin and the invariance of the quadratic law of growth, which clearly has operated since the origin of mankind. Today we are so preoccupied with information and education because humanity has reached the limit of the information society, when more effort is used to cope with information than with food or industry.

To depict scaling of the inherent processes of quadratic growth, a double logarithmic plot is the appropriate map. In this case, population N is plotted logarithmically beginning with one person and ending with 1 trillion (10^{12}) persons. Time, plotted in years, is counted from $T_1 = 2000$ and at this singular point a characteristic difficulty occures. If population numbers are positive integers, then time, reckoned from T_1, can be both positive and negative. In this case point 0 and its immediate surroundings have to be subtracted because zero does not have a finite place on a logarithmic graph. This is a graphic representation of how the blow-up singularity of growth at the demographic transition is eliminated. In this case, the logarithms of negative numbers are plotted on the negative half plane and logarithms of positive numbers on the positive half plane.

Three major epochs in the growth and development of humanity can be identified, and each is described by a scaling law. Epoch **A,** approximated by linear growth, began $T_0 = 4.5$ million years ago and corresponds to the onset of anthropogenesis. Quadratic growth describes Epoch **B**, which began to be conspicuous 2 million years later and lasted 1.6 million years dominating development. During Epoch **C,** quadratic growth abruptly culminates with the demographic transition. It began in 1955 and describes the transition to a stabilized population of the post-transition future. In Fig. 3.5, the points shown are from Biraben [54] and Cohen [122] (Table 4.1) and the estimate » 10^5 for the point 1.6 million years ago is from Coppens [27].

According to the mathematical model, a connection between the global population of $N_1 = 6$ billion at $T_1 = 2000$ and the effective life time t= 45 years, the age of humanity

$$T_1 - T_0 = t\sqrt{pN_1/2} = 4.5 \text{ million years ago} \qquad (3.3)$$

may be worked out. This expression, in a simple and direct way, only uses observed data to connect population at the moment of the demographic transition with the age of the human system.

On a log-log plot all growth that scales is described by a straight line. This indicates the self-similarity of growth and the constancy of the logarithmic rate of change because on a straight growth line all points are dynamically equivalent. As the hyperbolic growth curve (3.1) is transformed into a straight line, it begins at the point that represents the ten cosmologists 20 billion years ago and ends at $N_C = C = K^2 t = 176$ billion, the size of the

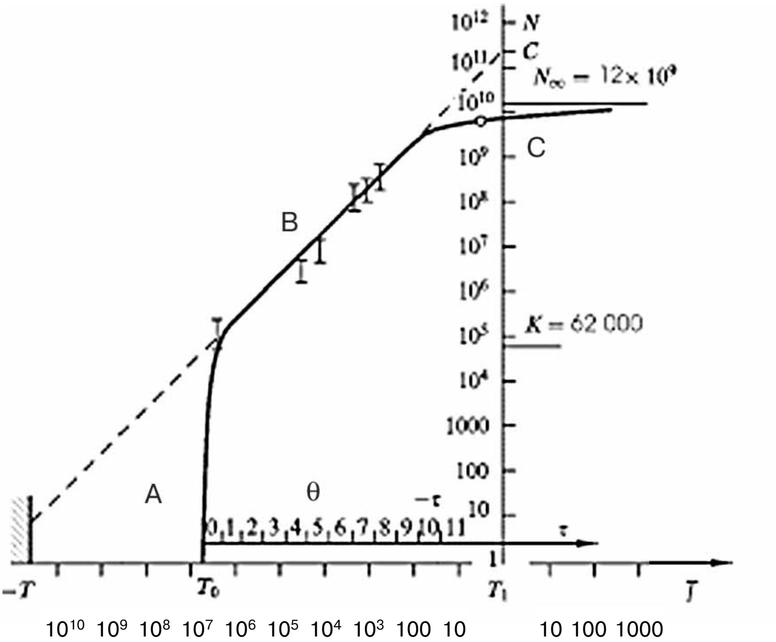


Figure 3.5. Global population growth from the origin of mankind and into the foreseeable future, described by the non-linear model $q = \ln t¢$, — — — — (3.1), ∘ — 1995

population one year before the blow-up singularity, if no cut-off were brought in to limit scaling. The double logarithmic plot vividly shows that the time scale is non-uniform and, when the demographic transition is approached, the time of development is compressed. If Epoch **A** lasted nearly 3 million years, the final cycle is only 45 years long. The demographic cycles, periodic in logarithmic time $q = \ln t¢$ reckoned from T_0 are also shown and will be described in greater detail in Chapter 5.

The double logarithmic plot provides the mapping appropriate for depicting global population growth and expresses the inherent properties of functions, which scale. Thus the double logarithmic plot is used to map self-similar quadratic growth, just as on a semi-logarithmic one plots exponential growth (see Figs. 1.1 and 1.2).

The passage through the demographic transition is best seen on a linear graph, when time and population are linear and linked at the singularity (Fig. 4.7). The initial stages of human evolution are also most clearly seen on a linear plot (Fig.4.2). This matching of plots expresses the correspondence of the analytic and graphic presentation of functions at different stages of growth and humanity's global growth and development can be described throughout all human history. In the framework of the model, it is due to the interaction based on intelligence and consciousness, new qualities which determine the accelerating growth of the human population. This development is primarily social, technological and cultural, and happened so rapidly that genetically determined evolutionary changes of mankind were not significant. For evolution is slow and quadratic growth is ever faster.

It is remarkable that growth, in the first approximation, depends only on the total number of people in the world. This striking result simplifies the analysis and mathematics, making the problem tractable. It also provides insight into the nature of the collective interactions, which statistically link growth and development. This is a crucial point and its resolution will provide a key to finally understand the nature of the global population system's non-linear dynamics and the interactions driving humanity's growth and self-organisation.

That the growth rate is determined by the global population at the time of growth could indicate that the system has no memory of the past. But in the main equation of growth (3.2) the population (and time) are really only average variables, spread out in time. In other words we are dealing with abridged equations, where all other variables are suppressed by the process of averaging. The averaging results in the relatively smooth character of global growth as the number of people multiply over the ages. This is the essence of the asymptotic methods and how the memory of the past taken into account. In the case of quadratic growth the time over which the effective averaging is implied, is proportional to the age of the moment of growth.

Thus mankind is seen as an entity — a superorganism or *anthroposphere* — coupled into an evolving demographic system by a universal, information-moderated interaction. This is a broad and challenging generalisation that is based on an interpretation of demographic, historical, and anthropological data using mathematical modeling. In this case the object is to describe the growth of the global population and interpret the factors of growth in terms of a generalized effective global interaction. This is fundamentally different from the methods practiced in demography. There growth is interpreted in terms of the local historic, social and economic factors present in society and determining its development. The approach in demography is limited both in time and space of a country or region. In global demography the space is that of the whole Earth and time covers the whole duration of the human story.

When comparing these two presentations it should be kept in mind that the local picture has to be seen on the backdrop of global growth as a part of the whole, and that is why it is of practical importance. On the other hand, local developments can illustrate and substantiate the global perspective. This is of significance at the time of the global demographic revolution when the rate of changes and the interaction is the greatest and expressed by globalization. In closing, all data used are generally accepted in the appropriate fields of study, including the monocentric theory of the African origins of the genus *Homo*.

Chapter 4
Population Growth and the Model

The unbelievable effectiveness of mathematics in natural sciences.

Eugene Wigner

4.1. The First Steps of Mankind

The global population growth model can be used to calculate the population of the world since the beginning of humanity. While demography and paleodemography provide population data for the world and different regions in the past, the accuracy of this data rapidly decreases as time is extended into the past. Instead of a direct census, paleodemography relies on indirect sources like tax records, reports of past battles and, for prehistoric times, indirect anthropological data. Nevertheless, as Braudel argues in volume III of *Capitalism and Material Life* [90], if the methods used to obtain these numbers are properly accounted for, the estimates make sense and contribute to quantitative studies of the past. On the other hand, the logarithm of past populations best represents population data because changes in the global population span orders of magnitude when they change over the ages.

Comparing the model with data from paleoanthropology and paleodemography provide a description of human development over a vast period of time. As Epoch **A** began some 4.5 million years ago it lasted approximately 3 million years. The model describes the initial period of anthropogenesis, when according to modern data, 4–5 million years ago hominids began to separate from the hominoids. By the end of Epoch **A**, *Homo habilis* appeared and the population of these primeval hominids reached about a hundred thousand. This estimate of the size of human

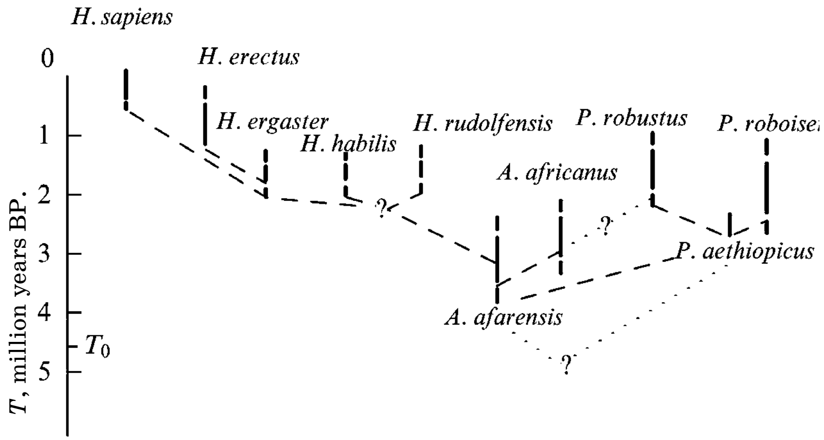


Figure 4.1. Philogenetic scheme for hominid evolution [25]

Based on recent analysis of hominid taxonomy the horizontal axis corresponds roughly to the relative and absolute postcanine tooth size, so that forms with substantial tooth rows are to the right, and species demonstrating premolar and molar reduction and simplification are to the left. The philogeny represented by the bold broken lines assumes that the two best known 'robust' australopithecine species, *P. robustus* and *P. boisei* shared a common ancestor which was not unlike *P. aethiopicus*. But, this monophiletic origin for *P. paranthropus* is only marginally more parsimonious than deriving *P. robustus* from *A. africanus*. The similarities in facial form between *H. rudolfensis* and a probable *Paranthropus* clade are most parsimoniously interpreted as convergent features

population at a turning point in the past is significant and was particularly important for the development of the model (Fig.3.5). I then consulted the great paleoanthropologist Yves Coppens, a professor of College de France, about the estimate because the population data for this period is sparse. Coppens led the French expedition to Africa and made major discoveries on the Lower Paleolithic following Leakey's work on early hominids in eastern Africa. Coppens estimates that 100,000 people lived 1.6 million years ago, which is remarkably close the number the model provided.

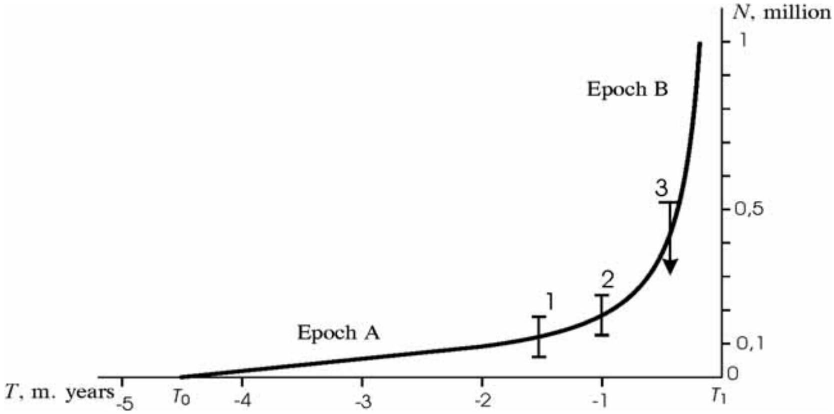


Figure 4.2. Initial stages of the growth of mankind

Estimates of population by: 1 — Coppens [27], 2 — Cohen [122], 3 — Weiss [22]. Compare with Fig. 3.5

This estimate is based on the observation that clans of some 100 early hominids inhabited approximately 1,000 sites throughout southern and eastern Africa, when the first tool-making hominids appeared in Africa at the beginning of the Paleolithic. Cohen cites Deevey's estimate that 125,000 people lived a million years ago [122]. After this initial period, most of the data fit the model within reasonable limits (Table 4.1). Thus, the model produces a plausible estimate that matches anthropological data for the time beginning 1.6 million years ago, when a critical step in human development occurred.

The gradual evolutionary process of anthropogenesis that culminated in *Homo habilis* in the framework of the model is essentially linear, as if the primordial biological system of hominoids gradually produced the new species. After this decisive point in human evolution, the collective nature of societal development, which follows quadratic growth, eventually took over and the evolution and development of the human mind became the driving factor of growth. At this critical stage of human development, a qualitative threshold that led to the emergence of the intelligent human, *Homo sapiens*, and the eventual blow-up growth of the human population was crossed.

When the co-operative social and technological pattern of self-accelerating development began, humans started to spread throughout the world and their population grew well beyond any other comparable species. Fluctuations in the sizes of the populations and different parallel evolutionary lines accompanied the initial process of evolution. The diffusion of humans throughout the world happened during the Pleistocene, when at least ten ice ages took place. These events are too specific for the generalized model because at this stage of human development large instabilities and competitive lines in evolution occurred. The last were the competition between Neanderthals and Cromagnon:

> ...from the morass of opinions in this notoriously contentious field, one consensus emerges: researchers have retired the old vision of the shuffling cultureless Neanderthal. Beyond that, whether these ancient hominids were among the ancestors of living people or a very closely related species that competed formidably with our own for the Eurasian territory and eventually lost remains to be seen. In either case the details will most likely be extraordinarily complicated [43].

In spite of these and other ambiguities, a plausible estimate for the beginning of anthropogenesis can be made by assuming linear growth during the emergence of the early *Homo.*

4.2. Influence of Climate and Geography

After anthropogenesis, human development and migration, which was driven by climate and geographical changes, can be traced through the ice ages. The geographical and climate changes that occurred during the last million years governed the spread of humans throughout the world and influenced the development of individual societies and cultures. Despite the great influence climate change and geography had on human development, it followed quadratic growth throughout Epoch **B** until the demographic transition information-moderated and largely independent of resources. According to the model, the midpoint of human growth reckoned on a logarithmic scale, was 10,000 years ago and marks the transition to the Neolithic (see Fig. 4.3 and 4.4).

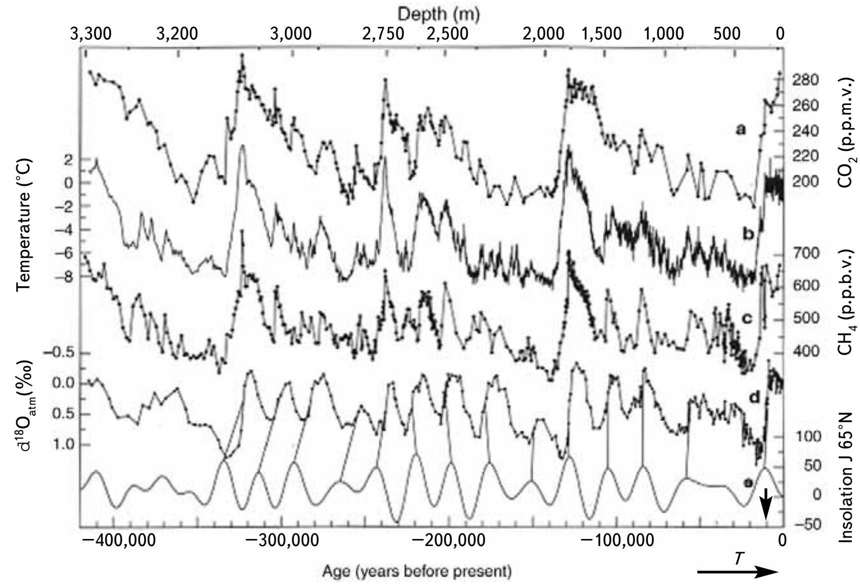


Figure 4.3. Climate of the past 420000 years from the **Vostok** ice core [41] (In Figs. 4.3 and 4.4 the original direction of time is reversed)

Vostok time series and insolation plotted with respect to time for the ice on the lower axis, with corresponding depths on the top axis of: **a**, carbon dioxide; **b**, isotopic temperature of the atmosphere; **c**, methane; **d**, atmospheric variations in oxygen-18 isotope, indicating temperatures and correlating with **e**, mid-June insolation, calculated for 65° North shown in watts per square meter

The Neolithic 10,000 years ago is marked ↓ on the linear scale of the climate changes during the past 420,000 years. This is the half way point on the logarithmic time scale of societal development (Table 5.3). On a linear scale, the whole time interval shown is only a quarter of the Stone Age. This vividly shows how the time of social development is transformed and compressed in human history.

Ice cores from Antarctica provide a remarkable record of past climate changes. In 1968, a Soviet expedition led by my brother Andrew Kaptiza, set up the Vostok station, trekking into the depth of the Antarctic ice sheet. The station is 3,450 meters above sea level and the average ambient temperature is −50 °C. The lowest temperature recorded at the station is −89 °C, is the lowest ever recorded on Earth. Kapitza measured the thickness of

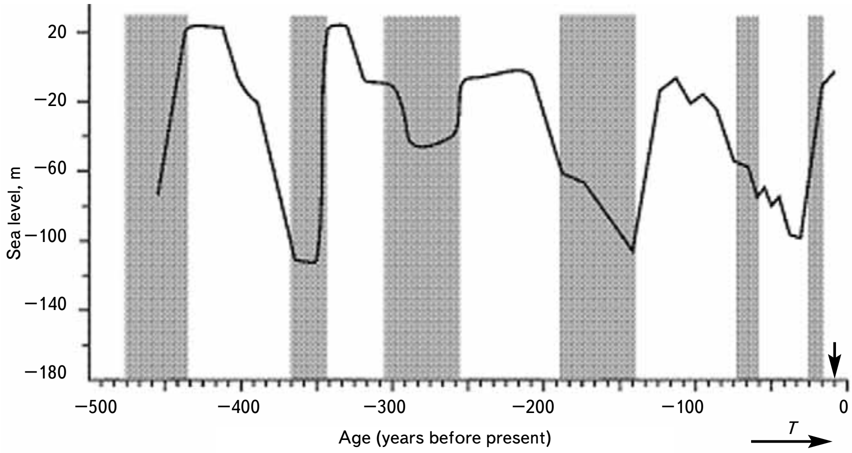


Figure 4.4. Climate change and sea level over the last 500 000 years. Based on studies of Red Sea coral reefs [40]. Glaciation during the Plio-Pleistocene shown in gray. The Neolithic is marked by ↓

the ice sheet at the Vostok station with seismic sounding, which provided important data on the glaciation in eastern Antarctica.

These measurements, data on the mean heat flux from the Earth's interior and the thermal conductivity of ice permitted me, by a 'back of the envelope' estimate to predict a positive temperature at the bottom of the ice sheet. A detailed examination of seismic records later confirmed this prediction and led to the discovery of a huge lake under the continental ice sheet [38].

At the Vostok station, a number of boreholes were made. They reached a depth of about 150 meters above the ice-water interface to avoid breaking into and polluting the lake, which may still contain life forms that have existed for a million years. The ice cores contain a remarkable record of the past climate and, in 1999 after years of meticulous analysis of the ice cores, an international group of scientists published data detailing the significance of the discoveries made in Antarctica:

> The recent completion of drilling at the Vostok station in East Antarctica has allowed the extension of the ice record of atmospheric composition and climate to the past four glacial-interglacial cycles. The succession of changes through each cycle and termination was similar and atmospheric and climate properties oscil-

> lated between stable bounds. Interglacial periods differed in temporal evolution and duration. Atmospheric concentrations of carbon dioxide and methane correlate well with Antarctic air-temperature throughout the record. Present day atmospheric burdens of these two important greenhouse gases seem to have been unprecedented during the past 420,000 years [41].

Later, using ice cores from another site, the data on the paleoclimate were extended to a million years into the past. Another record of past temperatures and sea levels is provided by the coral reefs in the Red Sea [40] (Fig.4.4). Measurements from the Red Sea and Antarctica substantiate each other and demonstrate the extent to which the climate has changed in the last million years. While this interval is relatively short in comparison to geological time, it was the most significant period of human development.

In the past, the climate and sea level changed within fixed limits, oscillating with a main period of 110,000 years. These oscillations are driven by the changing flux of solar energy reaching Earth, as its orbital motion and the direction of its angular momentum change. Variations in insolation have three periods with practically the same amplitude: a distinct long 110,000-year period, a 50,000-year period and a 40,000-year period.

These periods were worked out by Serbian physicist Milankovich in his theory of the ice ages. Although the forcing impact of the Solar flux is harmonic, the main response of the climate is dominated by the 110,000-year period with a typically non-linear pattern of rapid boom and slow bust cycle limited in its amplitude. However, the short period reaction of the climate system is linear, harmonic and has smaller relative amplitude. The difference in a short and long period response is a result of the complexity of the global climate system in which many factors contribute to climate changes. The most important factors are most likely the behavior of the biosphere and the ocean coupled in different ways. Water vapor, an active greenhouse gas, has a concentration closely linked to temperature and further complicates these changes [47]. Detailed observations show that an increase in temperature can precede an increase in greenhouse

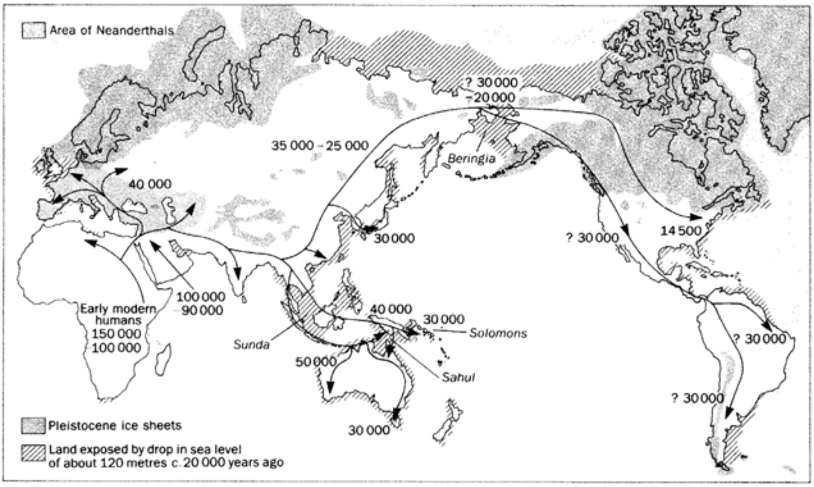


Figure 4.5. Migration of early hominids throughout the world [29]

gases illustrating how involved and interdependent climatic changes are. The complex behavior of the climate is an important factor in assessing the impact of human activities and greenhouse gases on global climate changes. Despite the great variations in past climates, humanity survived and multiplied, as it spread throughout the globe.

In Epoch **B**, growth and development mainly occurred on the Eurasian continent. During the ice ages, continental glaciers acted as a piston; they drove climate zones to the south that later receded to the north. These changes had a great influence on the human population, vegetation and animal species in the central latitudes of the northern hemisphere [39].

Geographical changes could have had a greater impact on the growth and development of humanity than climate changes. During the last ice age 40,000 years ago, the ocean level was 120 meters lower; the climate was much colder and drier than it is now. Asia and America were connected by a large land mass, the Behringia, which opened the way for the Western Hemisphere to be populated. When the sea rose, the Americas were cut off again and developed independently. The relatively small pre-Columbian population grew much slower than the considerably larger

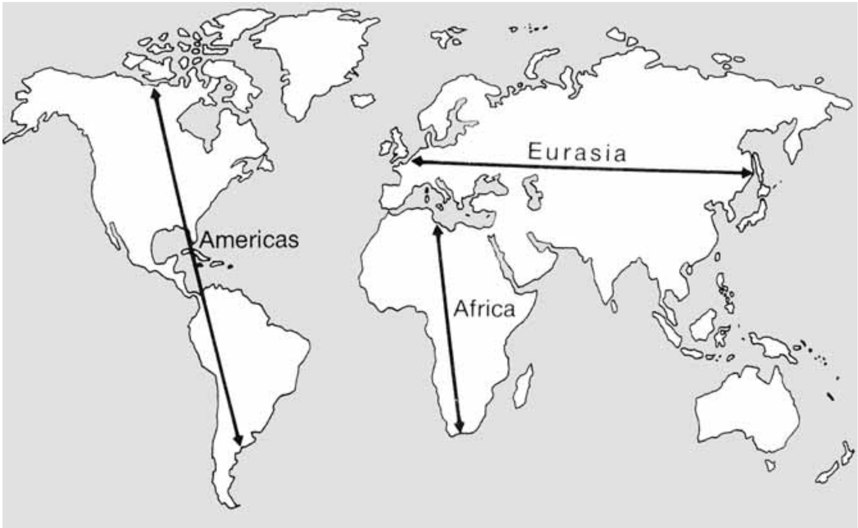


Figure 4.6. Major axis of the continents [39]

population in Eurasia, and because development is connected to numerical growth, the Americas lagged behind Eurasia.

In Guns, Germs, and Steel by Jared Diamond a general description of the large-scale history of humanity is presented [39]. Diamond argues that the shape and orientation of the continents was significant in human history. In the Americas, the distance between the north and south is 15,000 km, much greater than the continents' east-west span, which ranges from 5,000 km to 80 km (the Isthmus of Panama). Like Africa, the major axis in the Americas is north-south. In contrast, Eurasia's major axis is east-west. This facilitated a common pattern of development on the supercontinent as compared to in the Americas or Africa. The difference in geography and climate in Eurasia is much less than the climate and geographical differences in the Americas and Africa. Over these vast spaces, tribes migrated and people traveled transferring technology, ideas, crops and culture. On the other hand, shamanism, which appeared at least 100,000 years ago, was common to cultures in the Eastern and Western hemispheres and has survived up to the present [32].

Luca Cavalli-Sforza has shown how the slow evolutionary changes of man, migration and mixing can be traced using DNA markers [30]. This data on the early hominids can lead to an understanding of the transition from biological evolution that is governed by population genetics to the emerging capacity in human growth determined by information-moderated social development.

The development of language in the Paleolithic was an important, if not crucial, step in human evolution. The spread of languages is an indicator of humanity's common development and reveals connections going far back into the pre-Neolithic past. In an extensive study on Indo-European languages, Vyacheslav Ivanov and Tamaz Gamkrelidze showed how cultures spread over the last 10,000 years and demonstrated the interconnectedness of people and tribes, their growth and development [88].

In Archaeology and Language: The Puzzle of Indo-European Origins, Colin Renfrew discusses this subject [93]. Direct coupling through migration and the possibility of links without large-scale movements of people — links through the gradual diffusion of information — must be acknowledged when tracing the connections between tribes and cultures. In some cases, parallel evolution can take place, which shows how complex these processes can be. These connections occurred throughout the world as tribes migrated and civilizations grew, developing in a systemic and sustained, though turbulent and chaotic, pattern of growth and decay.

Another signal from the past is myths and legends, which have been carried in folklore through the ages. Customs and superstitions that originated in bygone times have survived in ancient rites, ghosts of cultures long gone. According to more detailed studies of past climate changes, there was a fast rise in sea level about 7,000 years ago. This rise has led to the speculation that a rapid, even catastrophic, event could have occurred. Practically every western and eastern mythology includes a story about a great flood or deluge. These stories, eventually included in the Bible, could well be mythological records of a real event. Regardless of the origin of the story of the Flood, major climate changes did happen in the past.

Studies of past climate change are of immediate and practical significance in assessing the impact of climate change on civilization. To properly assess these phenomena, long-term fundamental interdisciplinary studies of all relevant factors, which often include remote and unexpected phenomena, are needed. Ultimately, this leads to an understanding of past events and the future and to the assessment of the broad social and economic impact these processes may have. In studies of global issues, much has yet to be done. Any hasty conclusions, made under the influence of short-term interests, which are then multiplied and propagated by the media, are distracting. Ill conceived decisions can only compromise science and the authorities, who commit themselves to these poorly founded conclusions. Only when these matters are properly understood, can any meaningful statement be made on the impact of human activities on climate and the global consequences these changes will have.

4.3. Global population since the Neolithic

Since the Neolithic a global demographic system network of caravan routes began to span the world, at the same time as migration, wars and invasions connected the world over the vast steppes of Asia. In the last millennia, the Silk Road connected China and Europe with input from India. Ideas, religions, technical and social information moved along these great trade routes alongside goods and merchandise. An informative and detailed discussion of the impact of geography on our past may be found in *Mappa Mundi,* which provides a fascinating discussion how human system's were connected and gradually accelerated in their development, tied into a global entity [46].

After the Stone Age and the Neolithic, paleodemographic data and the model fit within the errors of all available estimates (Table 4.1). In general, both in history and anthropology, dates are known much better than population numbers because the accuracy of demographic data rapidly decreases in the past. For example, paleodemographic population estimates for 1 CE range from 100 million to 300 million. The discrepancy is mainly due to the input of China into the global population at that time.

Table 4.1. World population N and the results of modeling N_m (in millions)

Year	N	N_m	Year	N	N_m
$-4.4 \cdot 10^6$	(0)	0	1960	3039	3245
$-1.6 \cdot 10^6$	0.1	0.1	1965	3345	3497
–35000	1–5	2	1970	3707	3778
–15000	3–10	8	1975	4086	4089
–7000	10–15	16	1980	4454	4430
–2000	47	42	1985	4851	4801
0	100–230	86	1990	5277	5198
1000	275–345	173	1995	5682	5613
1500	440–540	345	2000	6073	6038
1650	465–550	492	2005	6453	6463
1750	735–805	685	2010	6832	6878
1800	835–907	851	2025	7896	7987
1850	1090–1170	1120	2050	9298	9259
1900	1608–1710	1625	2075	9879	9999
1920	1811	1970	2100	10400	10451
1930	2020	2196	2125	10700	10745
1940	2295	2474	2150	10800	10956
1950	2556	2817	2200	11000	11225
1955	2780	3019	2500	—	11731

Data of column **N** are from the 1999 documents of UN and Cohen [122]

The model indicates that the population was about 100 million in 1 CE, which corresponds to a joint statement by 58 Academies of Sciences on demography [71] and Forster's data [50]. Since the 14th century, after the great geographic discoveries, quality of global demographic data improves as the population system rapidly became interconnected, although interdependence, was always sustained, but took longer and longer the further one goes into in the past.

4.4. The Number of People Who Have Ever Lived

This table presents the available estimates of the population of the world and the results of the model. All through the vast period of population growth covering five orders of magnitude the model faithfully describes growth. The model also provides an estimate of the number of people who ever lived, which is of interest for studies in human population genetics and the origin of man. For this, the functions describing growth are integrated from T_0 to T_1 — from 4–5 million years ago to the year 2000. In total, about

$$P_{01} = 2.25\ K^2 \ln K = 100 \text{ billion} \qquad (4.1)$$

people lived during this period (A5).

By approximating population growth by a sequence of exponents Keyfitz [53] and Weiss [22] estimated that 80–150 billion people have ever lived. Recently, Haub estimated that 106 billion people have lived, which corresponds to the straightforward calculation in this model [81]. As is often the case in demography, the accuracy implied by Haub is certainly greater than can be expected. According to the model, about 5 billion hominoids lived during Epoch **A** rather than the 50 billion that Weiss estimates. This estimate of the early population of hominoids is made to account for the complex processes which led the final appearance of *Homo*.

Although the time scale for human development is vast, the human population system has now reached its maximum growth rate, a billion times faster than at the beginning of humanity. In Chapter 5, it is shown that the transformation and compression of the scale of time in history accounts for this acceleration of growth and development. The concept of the change in the scale of time finally leads to demographic cycles, which set a pattern for the gross structures of synchronous growth seen throughout the development of humanity.

4.5. The Future Population of the World

A linear plot of the global population on an expanded time scale near the demographic transition is shown in Fig. 4.7 rather than the blow-up represented by the sharp turn in Fig. 1.2. In Fig. 4.7, the agreement between population data and the calculated numbers before the transition is impressive and provides an opportunity to estimate the global population losses during the 20th century's world wars (Chapter 8). If the demographic transition cut-off did not occur, then, according to the blow-up model, the global population would have been 8 billion in 2000 — 2 billion more than the actual population — and would go to infinity in 2025.

The various projections for the future global population made using standard demographic methods and by assuming different futures are shown in Figure 4.8. Most of the projections ignore the real factors of growth and development. These assumptions, which express the general trends of the process of growth, are inevitably brought in externally, although they are not implicit to the process of development as in the case of modeling. Nafiz Sadic has remarked that in the past most demographic projections had been systematically revised upward [59]. At present, the opposite trend is taking place.

According to the Model, the global population will stabilize after the demographic transition and be asymptotically limited at $N_\infty = \mathrm{p}K^2 = 12$ billion. The population will reach about 11 billion, 90% of the maximum, in 2150. The Model indicates that the global population will stop growing and effectively double the population in 2000. According to the optimal UN scenario [78], which is based on fertility and mortality data in nine regions, the global population will stabilize at 11.6 billion in 2200. The projections made by IIASA cover a shorter interval, until 2100, and are based on six regions with ten different patterns of growth [60]. IIASA's optimal scenario 7 predicts a slow decrease of fertility and is similar to the UN's projections. After a revision of demographic data, the global population is seen to be growing at a relative rate of 1.4% a year (1999) and will reach 8.3 billion instead of 8.5 billion in 2025. In 1990, the projection was 5.29 billion and the growth rate was 1.7% a year. Independently, Akimov suggested that after 2100, the global population will stabilize at 11.6 billion [67].

The UN's *Long-Range World Population Projections Based on the 1998 Revision* [78] is listed in Table 4.1. The medium scenario states that the global population will stabilize at 9.7 billion

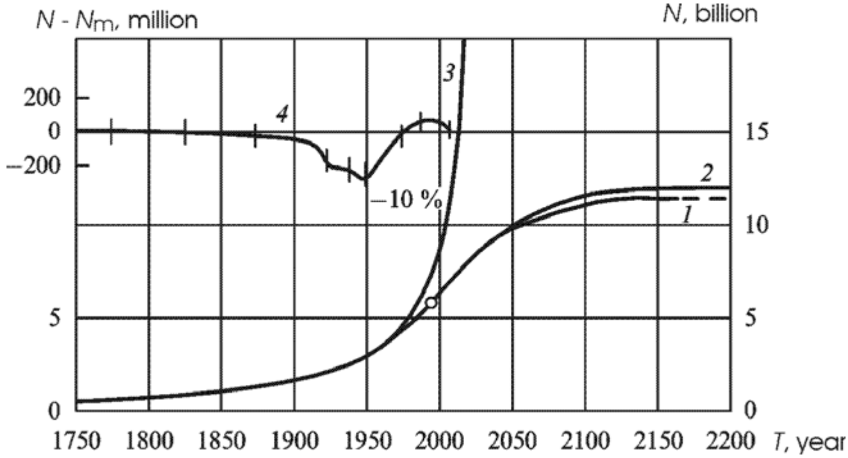


Figure 4.7. Population of the world from 1750 to 2200

1 — recent projections of IIASA and UN, 2 — Model, 3 — blow-up (3.1), 4 — difference between Model and global population, enlarged five times, showing losses due to World Wars I and II. ○ — 1995

in 2150. This projection is less than the 1996 Revision, which predicted that the global population would be 10.8 billion in 2150. These projections are based on the expected level of fertility. The 1996 Revision assumed that fertility levels would return to replacement-level fertility in every country.

In all, the following projections for year 2100 have been made by different agencies (see Table 4.2).

Table 4.2. Estimate of global population in 2100 (in billions)

IIASA	UN	World bank	Model
12.6±3.4	11.2–5.2+7.9	11.7	11 ± 1

The variations in the projections for 2150 are best seen when the three suggested scenarios are compared. The high scenario predicts that fertility will stabilize at TFR 2.5–2.6 children per woman. The medium scenario predicts fertility will stabilize at a replacement level of 2.05–2.09 children per woman, a rate leading to a constant population if there are no changes in mortality. The low scenario indicates how fast the population will decrease when fertility

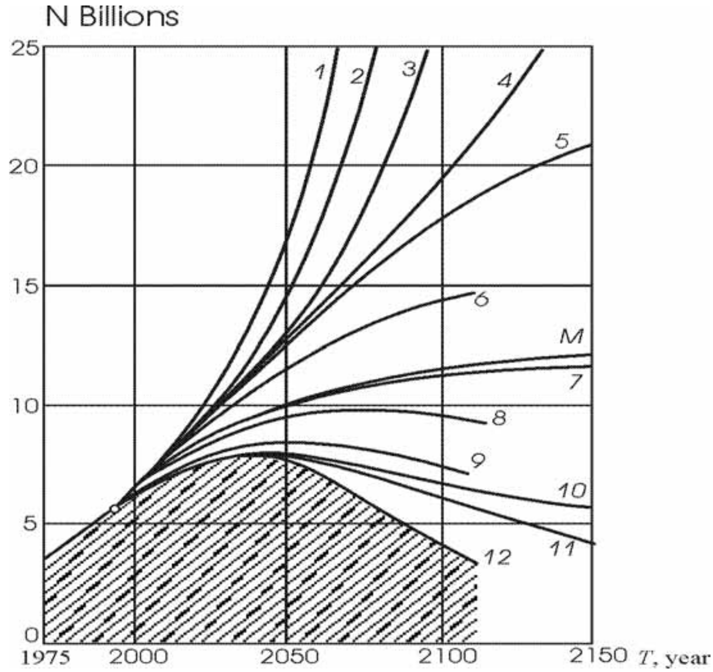


Figure 4.8. World population projections by the UN [63] and the International Institute for Applied Systems Analysis (IIASA) [66]

1 — constant fertility, 2 — constant rate of growth, 3 — Third World crisis, 4 — high UN, 5 — medium high UN, 6 — low decrease of fertility, 7 — medium decrease of fertility, 8 — slow decrease of mortality, 9 — constant mortality, 10 — medium low UN, 11 — low UN, 12 — rapid decrease of fertility. M — Model, ○ — 1990.

The shaded area shows the inevitable change in population in the case of drastic cuts in fertility.

stabilizes at 1.5–1.6 children per woman, about half a child below replacement level and will never stabilize as it rapidly goes to zero.

These scenarios project incredibly different global populations in 2150. The high scenario indicates a population of 25 billion, the medium scenario projects a stable population of 10 billion and the low scenario places the population at 3 billion with a rapidly decreasing population. This demonstrates the critical dependence of the post-transition world on the Total Fertility Rate (TFR), which may become the most critical parameter in the foreseeable future.

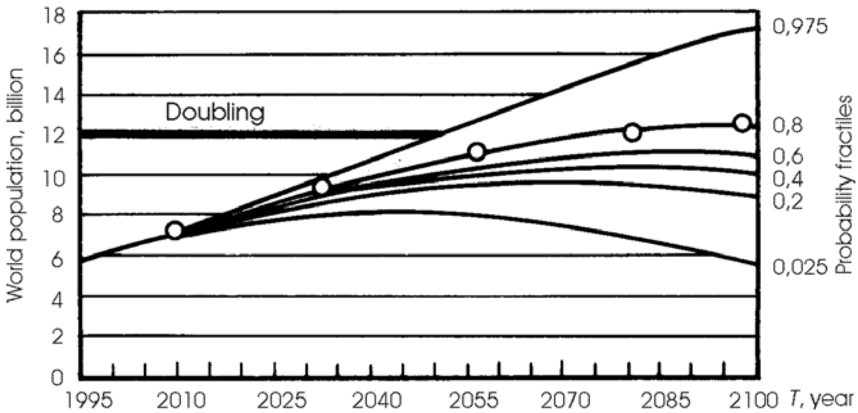


Figure 4.9. Comparison of Model -o-, and the projections of Lutz et al [77]

Lutz, Sanderson and Schcherbov predicted that the global population will effectively double and reach 11.6 billion ± 1.5 billion in 2100. The results are based on a multi-state cohort component models of 13 regions and are expressed in probabilistic terms [77]. The projections are made by applying assumed age-specific fertility, mortality and migration rates to an age and sex distribution and calculating a large number of possible paths of growth and then taking the average of these distributions. In effect, the calculations model both the uncertainties of the presumed trends in development and the data that is used in this global projection. Four sets of simulations were done and 4,000 projections were made.

In this massive mathematical experiment, the statistical nature of the global population is emulated by assuming a statistical approach to the global population system. By including migration in this probabilistic model some interaction between regions is included. These projections estimate that the global population will reach 7.9 billion in 2020 and 10 billion in 2050. The global population will reach a maximum around 2070 — 2080 and then experience a slow decline. By 2050, the authors have a 95% confidence level that the global population will be

8.1–9.1 billion, with an error of ±1 billion and note that:

> These probabilistic projections lead us to believe that the focus of public, political and scientific concern will shift from global population growth to population ageing.

This is very timely remark because the restructuring of the age pyramid, globally and in individual countries, is the main result of the transition to a stabilized global population. The 2003 projection of the UN Population Division estimates that the population will be 9 billion in 2300 [80] and, like the Model, the 2004 projection estimates that the population will be 9 billion in 2050 (Table 4.1). The percentage of elderly people (over 60) is 9.5% today and will increase to 20% in 2050 and to 27% in 2100. These numbers are known with a greater certainty than the global population itself. Richard Cincotta and Robert Engelman of Population Action International provide a detailed discussion of the validity and meaning of global population projections [79].

Modeling and projections indicate that the global population will stabilize. It should be noted, however, that demographic calculations are arbitrary not only when assuming a scenario, taken to be operative, but also because they are computationally unstable. A shift of 2-3 years in the change of fertility or mortality can lead to rapidly growing discrepancies and, in this case, calculations are only valid for short-range projections. On the other hand, the general agreement between estimates made by demographic projections and mathematical modeling is encouraging.

Probably more important than the comparison of numbers and the coincidence of trends is that basically different methods are being compared. The first are short-range linear projections or extrapolations combined with educated guesses. The second method is a general non-linear theory that describes the growth of humanity throughout history. That is why the comparison of these two approaches is of significance, as it shows how two different ways of analysis and forecasting produce similar results.

Chapter 5

The Sense of Time in History

The time is out of joint.
Shakespeare

5.1. Transformation of Time

The development of the human system in time shows that the rate of growth accelerates as the number of people increases. Thus, in history the sense of time of development becomes dependent on the growth of the world population. This coupling of time and growth leads to a greater understanding of the global interaction responsible for synchronous growth and the temporal structure of the population system.

From the concepts of the model it follows that the rate of growth is not constant in time for time and population are reciprocally connected: as the global population grows, the time scale is compressed. The demographic transition is the reference point from which change in the scaling of time should be seen. When the global population growth approaches the critical moment of transition, the time scale of humanity's rate of development becomes shorter and shorter as the rate of change gets faster and faster. This is a fundamental feature of the hyperbolic dynamics of the demographic system and leads to a quantitative understanding of the nature of the systemic acceleration of changes in the population system. The acceleration of development has been noted in historical studies for a long time. Now, the relative nature of time of change can be interpreted in terms of global demographic dynamics.

The relative growth rate is best expressed by introducing the exponential time T_e. By differentiating the growth rate, it is easy to show that for the global population up to 1950, the system's

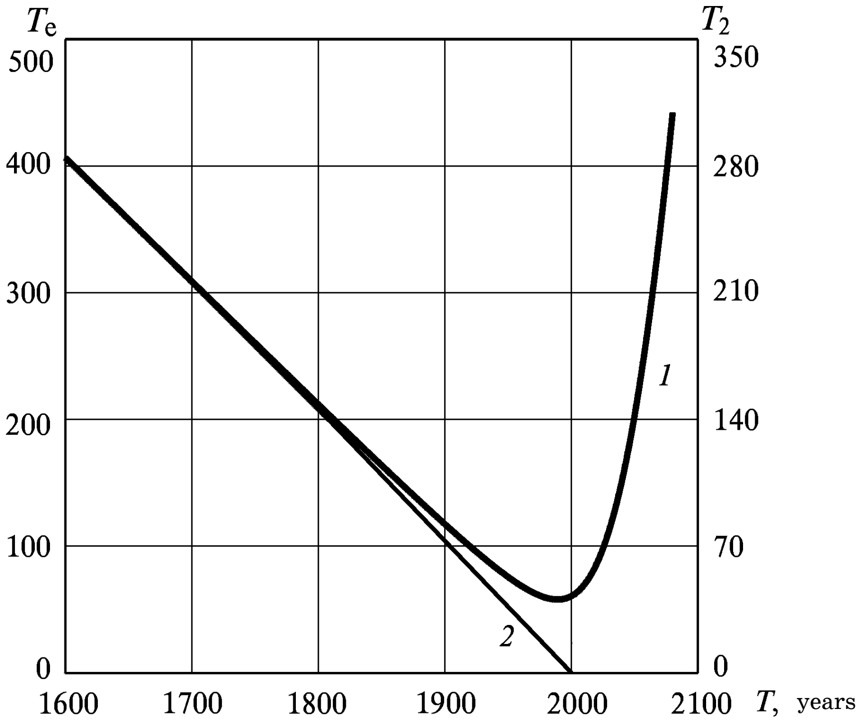


Figure 5.1. Exponential time of growth T_e and doubling time T_2 *vs* time T

1 — instantaneous exponential time of growth, 2 — linear approximation for past exponential growth time

instantaneous exponential time of growth is $T_e = T_1 - T$ and is simply equal to the time before present (BP). The annual relative global growth rate, customarily used in demography and anthropology to describe growth, is directly expressed by the reciprocal of the age of the event. A hundred years ago, for example, the relative annual growth rate was 1%. Two hundred years ago, the annual growth rate was 0.5%. Two thousand years ago, at the birth of Christ, the annual growth rate was 0.05%. Finally, 100,000 years ago the average growth rate was only 0.001% per year. These very low growth rates, which are well known to anthropologists, were poorly understood and, as no reasonable explanation or quantitative numerical treatment of growth had ever been suggested, some concluded that early human societies were static. Although the growth rate was very low, corresponding to the small population in the distant past, there has always been on the average self-similar growth that is dynamically of the same nature as growth that occurred throughout history. The only thing that is different was the large fluctuations experienced in those distant ages.

The further one goes into the past, more time was available, but the relative changes over T_e were the same. The result of scaling is the absence of an inherent and common unit of time for human growth and development, as the exponential time of growth is not a constant. Instead it follows the growth of the population system and gets shorter and shorter as the demographic transition is approached. At the beginning of Epoch **B** in the Lower Paleolithic, 1.6 million years ago, the human population was approximately 100,000 and the scale for marked change was a million years. At that time, it took about a million years for the population to increase by 150,000 people. Today, the global population grows by the same number practically every night.

What determined the growth rate in the distant past? The growth rate was definitely not limited by the birth rate, which was set by primordial reproductive instincts. Early humans had few taboos or customs that could have regulated the multiplication of these packs or tribes. The average growth rate was determined by the systemic survival rate of the humans who inhabited the planes and rifts of Africa at the dawn of human development and early social evolution. At that time, man began to grow and develop and slowly but surely established the pattern of systemic social development he has followed ever since. Regardless of the size of the birth rate or death rate, effective growth was determined by the extent the population system could be sustained by social development when asymptotically the system's growth rate is independent of the birth and death rates.

The first period of humanity's linear development, identified in anthropology as anthropogenesis, lasted at least 3 million years, leaving only 1.6 million years for all the rest of human development. The Oldowan period, the first period of the Paleolithic, lasted for about one million years. The period was named after the

Olduvai Gorge in Tanzania where Louis and Mary Leakey made the first discoveries of early hominids. After the end of the Oldowan period, all the rest of the development of the human system took half a million years — half of the duration of the Oldowai. According to the theory, this ratio of the duration of large-scale periods in human history to the time remaining to the present is true for any later period. For example, the Middle Ages lasted about 1,000 years (500–1500) and ended 500 years ago. During that time, the human population system, in relative terms, was developing thousands of times faster than at the beginning of humanity (Fig. 1.2). This expresses the change in the scaling of time and is a direct consequence of the compression of historically meaningful time. As time was compressed and development accelerated during each period, the population grew accordingly as a geometric progression, where the ratios of subsequent intervals are constant. Then the best way to view the past is to use ratios instead of differences of time and plot human development on a logarithmic time scale.

Archaeological dates, even dates from the Stone Age, can be established with some accuracy using cultural and technological markers. In most cases, the population is inferred from ideas about the lifestyle and technology of ancient cultures. For example, while archaeologists attribute the beginning of the Moustiere and the Neolithic with a rapid increase in population size, there is no direct demographic data that supports these conclusions (Fig. 5.2).

The Neolithic Revolution transition occurs close to $T_{1/2}$ = 11,000 BP. On a logarithmic scale the transition happened, when half of the human population system lifespan has passed and half of all the people who ever inhabited our planet have lived. By the Neolithic, the calculated global population was approaching 15 million, a number agreeing with most estimates [29]. Seen on a logarithmic scale, the past periods of mankind's growth and development are much closer to the present than when seen on a linear scale (Fig 4.3). This is a historically meaningful and sociologically significant way of viewing the past. Therefore the influence of the past should not be assessed in terms of generations or centuries, but in terms of this logarithmically transformed time.

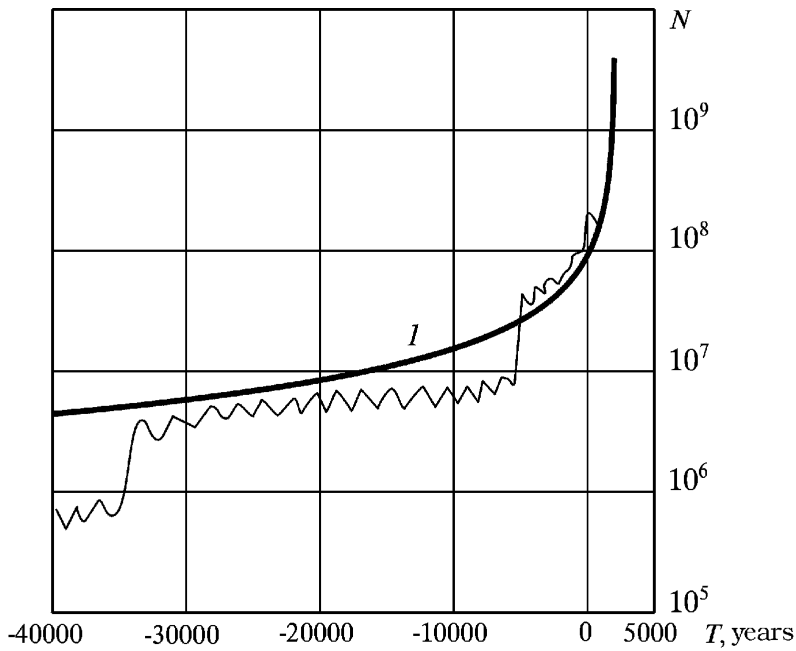


Figure 5.2. World population during the last 40 000 years [54] and the Model — (1)

In other words, when time is non-linearly aggregated there are 11 grand periods with equal transformed temporal space in history, instead of the 50,000 generations on a linear time scale. If the effective time of a generation τ refers to the personal and biological scale of growth, then the exponential time T_e sets the scale and the rate of societal and historical development. This is the outcome of asymptotic methods, which are effective because the scale of a generation and birth and death rates become less and less relevant to the whole process of growth and social systemic development the further away from the present they are.

The changing sense of time is a kinematic property of the model, a direct consequence of the kinetics of hyperbolic growth. As the blow-up is approached, exponential time is no longer a linear function of time and follows the exact expression (A33). In 1989, it passed through its minimum — 58 years — which corresponds to a relative annual growth rate of 1.7%, or a doubling time of 40 years. This indicates the speed the transition is passed and that an extended exponential pattern of growth is never followed (Fig. 5.1). After the demographic transition, the population stabilizes and the growth rate decreases as the square of time. In the post-transition era, the structure of time will change and a new connection between population growth and development will emerge. This pattern is to differ greatly from the hyperbolic growth before the transition that is now culminating in the demographic explosion.

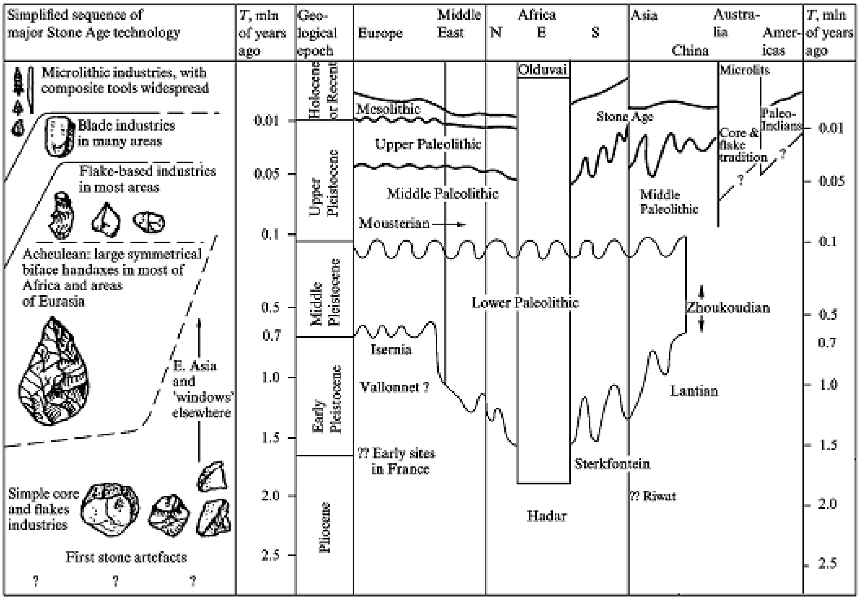
5.2. Transforming the Time of History

The transformation of time during Epoch **B**, when the intervals form a geometric progression, should be compared with periods identified by anthropology and global history. When seen on a logarithmic scale, all major periods since the beginning of the Lower Paleolithic are more or less equally spaced on a logarithmic scale as shown in Tables 5.1, 5.2 and 5.3. Table 5.1 also shows the diffusion of humanity throughout the world and illustrates the synchronism of the main periods of the prehistoric past.

The logarithmic scale was traditionally used to plot anthropological data because otherwise it would be difficult to accommodate the Neolithic (10,000 years ago) and the Lower Paleolithic (1 million years) on a linear scale. On the other hand, archaeologists found that the best way to present data about the oldest periods was on a linear scale (Table 5.1), similar to how the model describes Epoch **A.** Although the estimated duration of Epoch **A** provides a plausible date for the beginning of the complex events that culminated with the appearance of *Homo habilis*, the estimate is in no way a detailed model of the early stages of humanity's evolutionary development.

Table 5.2, plotted on a logarithmic scale and counting time from the present, summarises humanity's development and shows that the generally established chronology, compiled by Italian anthropologist Faccini, practically coincides with the dates calculated in

Table 5.1. Stages of the Paleolithic [29]



the model [28]. The names of some periods do not always match those in Tables 5.1 and 5.3, which show the diversity of terms and opinions in this difficult field. For example, the Chelles period, which comes before Achelle, is omitted even though it is implied by the accepted chronology and the data presented in Table 5.2. The Mesolithic is also difficult to identity. (See also [97].)

The entire course of human development is summarized in Table 5.3, which show the transformation and compression of time on a logarithmic scale. The periods, identified in anthropology and history, are shown from humanity's beginning 4–5 million years ago through the critical year 2000 of the demographic transition to when the population stabilizes at 10 to 12 billion.

In Table 5.3, the periods are identified as demographic cycles, although no direct demographic data can substantiate the existence of a cycle, for even in recent cycles there are no observable discontinuities in growth rates to mark a cycle. On the other hand, historians and anthropologists generally recognize and use

Table 5.2. Periods of the Stone Age according to Faccini [28]

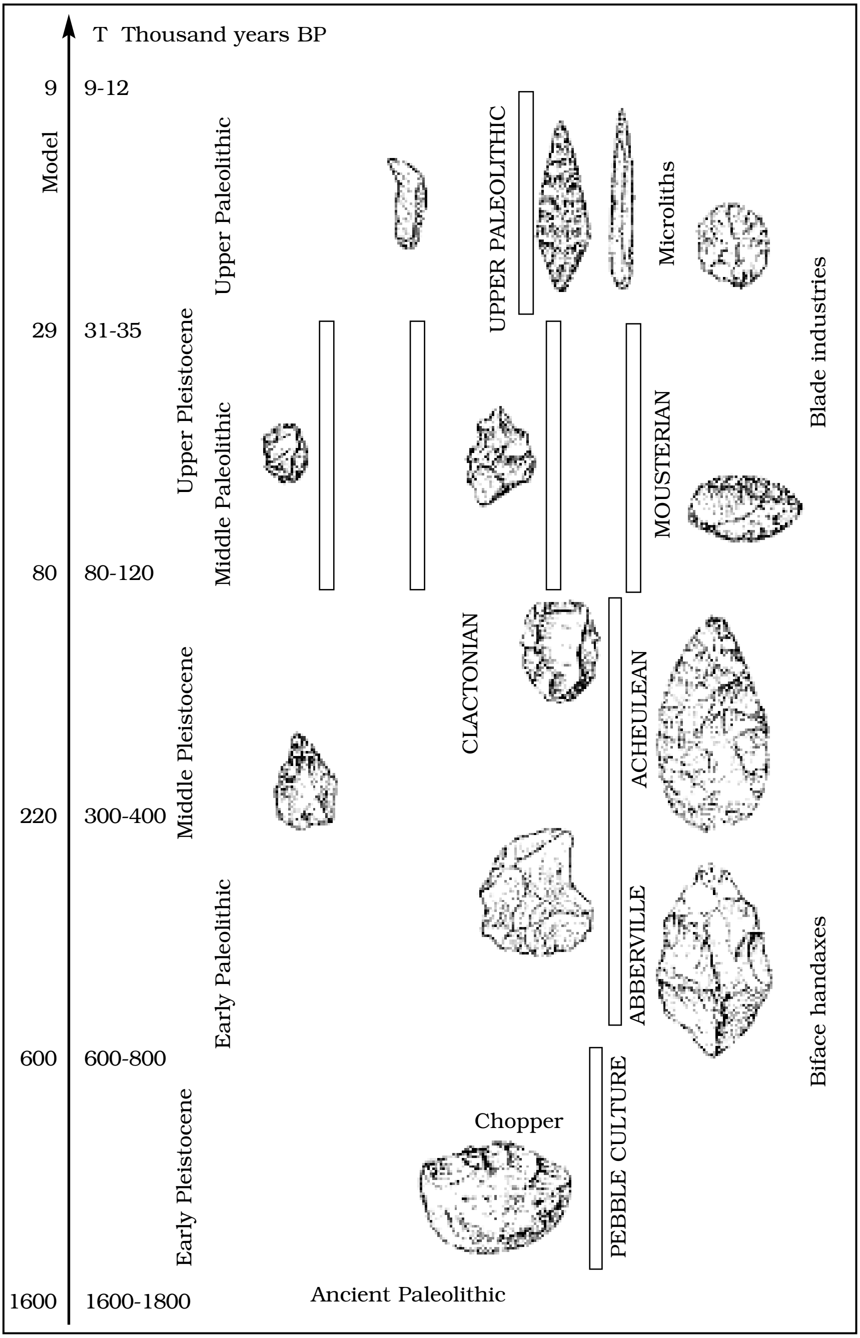


Table 5.3. Growth and development of mankind, shown on a logarithmic scale

Epoch	Period q	Date year	Number of people	Cultural period	DT years	Events in history, culture, and technology
C		2200	11×10^{9}	Stabilizing global population		Global population limit 12×10^{9} Changing age distribution
		2050	9×10^{9}		125	Globalization
	T_1	2000	6×10^{9}	World demographic revolution	45	Urbanization Internet
B	11	1955	3×10^{9}		45	Biotechnology Computers
	10	1840	1×10^{9}	Recent	125	World Wars Electric power
	9	1500		Modern	340	Industrial revolution Printing Universities
	8	500 AD		Middle Ages	1000	Geographic discoveries Fall of Rome
	7	2000 BC	10^{8}	Ancient World	2500	Christ, Muhammad Greek civilization Axial time India, China, Buddha, Confucius
	6	9000		Neolithic	7,000	Mesopotamia, Egypt Writing, Cities Domestication, Agriculture
	5	29,000	10^{7}	Mesolithic	20,000	Bronze Microliths
	4	80,000		Moustier	51,000	America populated Shamanism
	3	0.22 Ma	10^{6}	Acheulean	1.4×10^{5}	Language *Homo sapiens* Speech, Fire
	2	0.6 Ma		Chelles	3.8×10^{5}	Europe and Asia populated Hand axes
	1	1.6 Ma	10^{5}	Olduvai	1×10^{6}	Choppers *Homo habilis*
A	T_0	4.5 Ma	(1)	Anthropogen	3×10^{6}	Hominida separate from Hominoids

the periods, which are identified by technological and cultural markers.

Each period in Epoch **B** corresponds to a demographic cycle, which can be identified as phases in physics. The number of cycles during Epoch **B** is determined by ln $K = 11$ and can be seen in expression (4.1 and A19) which shows the total number of people who ever lived. While the duration of each period decreased from 1 million years to 45 years, a constant number of 9 billion of people lived during each cycle. In the framework of the Model some 5 billion people lived during anthropogenesis and 12 billion people will live during the demographic transition, which is to last 90 years. This cyclic pattern of periods is a sequence of intervals of a geometric progression when each cycle is 2.5 to 3 or $e = 2.72$ times shorter than the preceding cycle and the population increases in the same proportion. It is surprising how well the calculated dates correspond to the observed cycles, which are based on meticulous work by generations of archaeologists to identify the slightest differences in tools of Stone Age industries. The dates are mostly determined by carbon dating and geological evidence.

The theory of phase transitions in evolving non-equilibrium systems is relevant in this case and it can be suggested that these cycles could be classified by their strength [154]. The first is the transition that led to the appearance of the human brain and mind, a singular and decisive step in human evolution. All subsequent cycles are marked by transitions of a lesser order, except the Neolithic and the final one. The Neolithic, right in the middle of Epoch **B**, is also special because the distribution of humans in space changed from diffusion to concentration into villages and towns. While weaker than the first and last cycles, it is an intermediate transition and stronger than the other phase transitions. As the Neolithic belongs to the second half of Epoch **B,** this supports the recently accepted opinion that the Neolithic is part of history rather than pre-history. The final phase transition, the demographic transition, is the strongest of all. In this transition, which is proper to call a revolution, the paradigm of human growth and development goes through a fundamental change.

In *The Paths of History*, Russian historian Igor Diakonoff argues that the sequence of large-scale features in the post-paleolithic explicitly follows a geometric progression that culminates with a singularity:

> Without doubt the historical process demonstrates all the features of exponential acceleration. From the appearance of *Homo sapiens* at the end of phase I, 30 000 years have passed. The subsequent Phase II lasted approximately 7000 years, Phase III — 2000 years, Phase IV — 1500 years, Phase V approximately 1000 years, Phase VI — 300 years and Phase VII not much longer than 100 years. Plotted as a curve these phases add up to exponential growth, which will lead to a vertical line or to be accurate, to a so-called singularity. An exponential pattern describes the technological and scientific development of mankind and, as has it been mentioned, the Earth's population growth. A vertical line on a graph is equivalent to a blow-up to infinity. For history the concept of infinity has no meaning: the following Phases of historic development cannot accelerate, when phases will change in years, months, weeks, days, hours, or seconds. If no catastrophes are foreseen — and we can hope that with all his wisdom *Homo sapiens* will manage to avert them, it is obvious that we have to expect the interference of new, unknown forces, which will change this trend. This will be fine, if they guide us to a plateau but unfortunate, if it is to lead to a rapid decline from some high point. We can only hope that mankind will soon enter a phase of slow or zero growth.
>
> Prognostications have not up to now been the duty of historians. One cannot but think what will happen after Phase IX of the historical process, a phase that is to follow post-capitalism. One can rely on God and the tens of billions of immortal souls that have lived on Earth in the past. But one has to keep in mind, that to believe in God of the Gospel is to believe in the Apocalypse [101].

This passage shows the similarity between the model and the observations of a historian. Although Diakonoff identifies cycles as phase transitions, he offers no explanation of this phenomenon. Yury Yakovetz discusses the acceleration of the rate of development in history. He compares the temporal extent of world civilizations by introducing the ratio of the duration of the subsequent periods [100]. These ratios vary from 1.5 to 2.3 and show that historically relevant intervals from the Neolithic to 2130 are periodic on a logarithmic scale, though Yakovetz did not introduce a zero point for the logarithmic scale. Modelski discusses the evolution of man since the Neolithic and presents arguments similar to the theory, but without quantitative results [124].

There have been many other attempts to set up a sequence for periods in history. Arnold Toynbee, in his monumental *Study of History*, identified 21 civilizations that were limited geographically and differed socially and by religion. These civilizations are not global and cannot be described by a global model, although they should be examined in the broader perspective of the logarithmic time scale. Other historians differ in identifying the gross features of the past. For example, the Ancient world is split up and other cycles are named differently. Generally though, these differences, with some slight shifts in the chronology, do not change the interpretation based on the phenomenological theory of growth.

It can even be suggested that the authors of the Old Testament had an intuitive understanding of an expanding time scale in the past, and expressed it by ascribing excessive ages to the oldest Pre-Noachian patriarchs (Methuselah was 969 years old, Gen. 5:27). The transformation of time works for large-scale historic events. For example, the history of ancient Egypt spanned 3,000 years and came to its end 2700 years ago. According to Gibbon, the decline of the Roman Empire to the fall of Constantinople in 1506 took 1,500 years [82]. At times close to the demographic transition, empires built in centuries collapse in decades, if not less, driven by the accelerating clock of history, as the scale of growth changes. Dynasties were a measure of Egyptian and Chinese history, a numbered sequence of kings and queens was used for European history and now, there is no time left to establish a long-term temporal series based on the continuance of the political and economic fabric of society.

As Braudel and Konrad [87] discuss, much has been done by historians to match periods in European history with those of the East. UNESCO published a systematic review of history written by an international group of authors [97]. In seven volumes, the evolution of humanity is described with special emphasis on a balanced presentation of non-European civilizations. Most charts of global civilizations show that large-scale features of the past are synchronous throughout Eurasia. Thus, historians, who have insight and a well-developed intuitive base but rarely express their findings in quantitative terms, have come to conclusions close to those derived from mathematical modeling. Historians have definitely recognized that the time of social development has been transformed and compressed, as the present is approached and the population blows up at the demographic transition.

The temporal structure of history and pre-history, which has evolved for more than a million years, has come to its end because time cannot be compressed any more. As a meta-historical idea, the contracting time scale supports the concept of systemic development of humanity. It expresses both the immanent nature of the population imperative and indicates the general agreement of the model with the ideas and vision of historians about the temporal structure of history seen at large.

5.3. The Beginning of the Scale of Time

The idea of a changing, non-uniform time scale is based on the systems dynamics of mankind's growth. The changing time scale leads to a logarithmic time scale with a beginning and an end, or rather, a transition to a new mode of growth and development.

Sheet music can be used to illustrate the difference between a linear and a logarithmic time scale. The temporal running of the score is linear and has no inherent beginning or end. On the other hand, the pitch, the inverse time of the period of the tune, in musical notation is shown by the horizontal bars where signs, representing the tune, are placed on. In this case, the scale is logarithmic and, with various modifications, can cover ten octaves. These limits are imposed by the range of frequencies covered by human hearing — approximately from 20 to 20,000 cycles per second. The temporal duration covers the same range of 1,000 (2^{10} » 1000) and runs in the opposite direction to the frequency. Similar to descriptions of history, it is impossible to cover this range using a linear scale. Therefore, both a linear and a logarithmic scale are used on a score. The scale for the tunes matches man's perception of sound, because human hearing is inherently logarithmic in the way it reacts to the frequency ratios of tones. Man's sense of the volume of a sound is also logarithmic — loudness is measured in logarithmic units of decibels.

The choice of an origin, the zero point on a calendar, is really arbitrary. In the Christian world, the birth of Christ is used as the zero point. The Greek Orthodox Church uses 5508 BCE, the date Emperor Constantine pronounced as the origin of the world. Islam uses 622 CE, the year Muhammad's flight from Mecca to Medina occurred, as the beginning of the age of Hizdra. These time scales are based on religious teachings and use the astronomical year as the unit of time. For the Muslim, Hebrew, Buddhist, Chinese, or any other calendar not tied to the birth of Christ can have no numerological or mystic significance. Similarly, from a detached scientific point of view, all public expectations associated with a turn of a century or a new millennium have no real meaning. In *The Magic Mountain,* Thomas Mann notes:

> Time has no divisions to mark its passage; there is never a thunderstorm or a blare of trumpets to announce the beginning of a new month or year. Even when a new century begins, it is only we mortals who ring bells and fire off pistols.

In the western calendar, misunderstandings as to whether to celebrate the arrival of the 21st century on 1 January 2000 or a year later arose because there was no zero year in the way time was reckoned in the past:

. . 3 2 1 0 1 2 3 2000
BCE IV . . . III . . . II . . . . I . . . . II. . . . III . . . IV . . XXI →

↑ First century before Christ

↑ First century after Christ

↑ 21st Century CE

Astronomy uses the first sequence of dates, while ancient writers developed a second sequence to number the years and centuries before and after the birth of Christ. The difficulty is in the concept of zero in a linear representation of time. It is similar to a logarithmic chart, which also has no place for zero (Fig. 3.3). That is why, by subtracting the singularity at T_1, the divergence of the hyperbolic blow-up, which leads to the demographic transition, is removed.

The point zero already upset those who worked out dates on a calendar before the idea of 0 and negative numbers at an arithmetical level had been developed. For example, there is no way to represent zero in Roman numerals. In regard to when the new millennium should have been celebrated, scientifically minded people should have celebrated it on the eve of 1 January 2000, but if a traditional approach was taken, you had a second chance to celebrate on 1 January 2001.

After the French Revolution, a new calendar was decreed, born in those violent years of disruption. Similarly, after the October Revolution of 1917, extremists in the Soviet Union attempted to introduce a new calendar in 1929. These ideas were short lived and never adopted. They are reminders of the political vanity of those, who proposed these weird suggestions. Similar ideas were recently revived in Turkmenistan.

The year 2000 signals a change in the paradigm of human development and, for that reason it is a singular time, a special moment in the growth of the human system. It is significant, because the turn of the millennium practically coincides with the high point of the global demographic transition, though this is rarely mentioned. Nevertheless, for any physically meaningful theory, the description of humanity's growth and development has to be invariant to any shift of the origin or change in the time scale because Newtonian time is uniform.

Time could be measured from T_0 = 4.4 million years ago as is done in describing Epoch **A**, and logically this would be preferable. It would, however, be impractical to use this system of reference to describe recent events, particularly since there is no known event to which to tie down the time scale. Epoch **A** is perceived as an extended period in the early stages of anthropogenesis, rather than a moment, even a hypothetical one, in the past. But T_1 can be used even when it occurs before the present, as the moment of transition is a profound and veritable revolution — the demographic revolution.

While shifting the time of the origin on a logarithmic scale is conceptually easy, it is technically difficult. On a non-uniform logarithmic time scale, there is no place for zero and no linear invariance to shifting time; to add or subtract time, one has to go back to a linear representation of time. On the other hand, the logarithmic time scale brings the cut-off and the characteristic human unit of time into the model. The conjugate symmetry between time and population in the mathematics of the theory is a fascinating feature of the model. When time is dilated in the past and compressed as the population blows up at 2000, the reciprocal connection is clear in the asymptotics of hyperbolic growth when the size of the population is small in the past and goes to infinity at the population explosion.

American historian Francis Fukuyama said that we were living at the end of History [94]. What he seems to have meant is that our ideas about history have reached a limit and must be changed to include globalization, etc. Global demographic modeling shows that a much more profound change is happening. Not only has the old pattern of growth come to an end, but humanity is passing into a new phase of development. History, the human story, will certainly continue, although its rate and nature will change. The dynamics of global demography are signaling these changes.

In this analysis, a quantitative approach was developed to depict the grand pattern of human history. Any quantitative study begins with measurement, an expression of a parameter in terms of a number of the units used. The year, a numerical unit, originates from the orbital motion of the Earth. The natural unit of time for the human system is 45 years. The unit for population is one person and the unit for a population subgroup is $K = 62{,}000$ people. The essence of the quantitative method is the choice of scale and units. For example, the abrupt change in the course of history — the growth rate — is easily seen in Fig. 1.2, where the time scale extends over many thousands of years. In Fig. 4.5, where the time scale spans decades rather than millennia, the same transition, when magnified, looks smooth and gradual. Many phenomena and all transitions in history and physics are best expressed by a change in scale.

The intuition, insight and conjectures of historians and social scientists support results from mathematical modeling, which are based on reasoning that comes from a quite different set of premises and ideas. In the course of this study, we have this 'meeting of minds' between the humanities and the hard sciences.

5.4. Synchronism of Global Development

Since the scaling of world history was recognized, the simultaneity of the main features of global development has become a subject of study and debate for historians and anthropologists. In the case of the global population system, the existence of such a system means that it evolves and changes as an entity. The global synchronism of transitions is a direct result of interactions in the population system and indicates systemic behavior since the beginning of social evolution.

The time of a transition is usually marked by the appearance of a new technology or a social change, which then spread throughout the world. The nature and synchronism of history is a subject of major concern because historians often pay more attention to the diachronic development of different regions than to the simultaneity of large-scale structures. This has to be discussed, taking into account the findings and ideas of social sciences — primarily history — in treating the development of humanity on a large scale not only in terms of numbers, but also in terms of events. Braudel expresses and illustrates the power and meaning of this point in interpreting world population growth:

> **Guessing the world population**
>
> The difficulty is that even today if the world population is only known within a 10% margin of error, our information concerning earlier populations are even less complete. Yet everything, both in

the short and long term, and at the level of local events as well as on the grand scale of world affairs, is bound up with numbers and fluctuations of the mass of people.

Ebb and flow

Between the 15th and 18th centuries populations rose or fell; everything was in a state of change. When the number of people increased, production and trade also increased. Wasteland and woodland, swamp and hill came under cultivation; manufactures spread, villages and towns expanded, the number of men on the move multiplied; and there were many other positive reactions to the challenge set by the pressure of population increase. Of course, wars and disputes, privateering and brigandage grew proportionately; armies or armed bands also flourished; societies created *nouveaux riches* or new privileged classes on an unusually large scale; states prospered — both an evil and a blessing; the frontier of possibility was more easily reached than in ordinary circumstances. These were the symptoms. But demographic growth is not an unmitigated blessing. It is sometimes beneficial and sometimes the reverse. When population increases, its relationship to the space it occupies and the wealth at its disposal is altered. It crosses critical thresholds and at each one its entire structure is questioned afresh. The matter is never simple and unequivocal. A growing increase in the number of people often ends, and always ended in the past, by exceeding the capacity of the society concerned to feed them. This fact, commonplace before the 18th century and still true today in some backward countries, sets an insuperable limit to further improvement in conditions. For when they are extreme, demographic increases involve deterioration in the standard of living; they enlarge the always horrifying total of the underfed, poor and uprooted. A balance between mouths to be fed and the difficulties of feeding them, between manpower and jobs, is re-established by epidemics and famines (the second preceding or accompanying the first). These extremely crude adjustments were the predominant feature of the centuries of the *ancienne regime*. But the main point for the observer is that everything takes place within the framework of vast and more or less observable movements.

We can pinpoint a prolonged population rise in the West between 1100 and 1350, and another between 1450 and 1650. A third, after 1750, was not followed by a regression. Here we have three broad and comparable periods of biological expansion. The first two, which occurred in the middle of our period, were followed by recessions, which were extremely sharp between 1350 and 1450 and decidedly severe between 1650 and 1750. Nowadays any growth in backward countries brings a fall in the standard of living but fortunately not a decline in numbers (at least not since 1945).

Every recession solves a certain number of problems, removes pressures and benefits the survivors. It is pretty drastic, but none the less a remedy. Inherited property became concentrated in a few hands immediately after the Black Death in the middle of the 14th century and the epidemics, which followed and aggravated its effects. Only good land was cultivated (less work for greater yield). The standard of living and real earnings of the survivors rose. Thus in Laguedoc between 1450 and 1550 the peasant and his patriarchal family were masters of an abandoned countryside. Trees and wild animals overran fields that once had flourished. But soon the population again increased and had to win back the land taken over by animals and wild plants, clear the stones from the fields and pull up trees and shrubs. Man's very progress became a burden and again brought about his poverty. From 1560 to 1580 onwards in France, Spain, Italy and probably the whole Western world, the population again became too dense. The monotonous story begins afresh and the process goes into reverse. Man only prospered for short intervals and did not realize it until it was already too late.

But these long fluctuations can also be found outside Europe. At approximately the same times China and India probably advanced and regressed in the same rhythm as the West, as though all humanity was in the grip of a primordial cosmic destiny that would make the rest of man's history seem, in comparison, of secondary importance. Ernst Wagemann, an economist and demographer, held this view. The synchronism is evident in the 18th century and more than probable in the 16th. It can be assumed that it also applied to the 13th and stretched from the France of St. Lois to the remote China of the Mongols. This idea would both shift and simplify the matter. 'The development of population — wrote Wagemann — must be attributed to causes very different from those that led to economic, technical and medical progress'. This is a remark to bear in mind. Obscure, yet prophetic in its way, it will help towards a better grasp of an authentic history of the world.

> In any case these fluctuations, which occurred more or less simultaneously from one end of the inhabited world to the other, make it easier to envisage the existence of numerical relationships between the different human masses which have remained relatively fixed over the centuries: one is equal to another, or double a third. When one is known, the other can be worked out; eventually, therefore, the total for the whole body of people can be assessed, though with all the errors inherent in such an estimate. It is tremendously important to work out this global figure. However inaccurate and inevitably inexact, it helps to determine the biological evolution of humanity considered as a single entity, a single stock as statisticians would say [90].

It would probably be difficult to find a better statement from a historian on the concept of the global population system that so completely matches and substantiates the ideas of the theory of population growth. The systemic nature of humanity and the similarity in the development of its gross features, immediately leads to conclusions on the nature of the synchronizing agent in development of the global population system.

A significant and universal period in human history was from 800 BCE to 200 BCE when major religious ideas and many of the fundamental moral concepts of humanism which underlie civilization were developed almost simultaneously in the East and West. German philosopher Karl Jaspers identified this 'axial' time in *The Origin and Goal of History* [86]. The book opens with following potent words:

> In all the life of man the changes of our time are crucial in their breadth and depth. Only the history of mankind as a whole can provide a scale for understanding what is happening right now.

This is a proper summary of the discussion of the synchronism of global history seen at large in terms of population dynamics and systemic behavior.

The major cycles in world history should be seen as temporal structures that overshadow regional features, fluctuations in growth and disparities in industrial and social development, rather than as a sequence of events. The cycles have manifested themselves throughout history in every country and region in the world and supersede kingdoms, dynasties, wars and conquests. Nevertheless, historical narratives and personalities are usually more captivating and tend to dominate descriptions and explanations of the past. Disparities do and should exist, as perturbations of the basic cyclic structure, but do not challenge the grand timetable of human development. In the case of the overall pattern of human development, the obvious and the usual must give way to the big picture. At this greater scale, the synchronism of global development can be seen best and then the concept of transformation of time in history become relevant.

5.5. The Concept of Time in History

Philosophers and historians have written an immense amount on the meaning of time in history. Two meanings of time were identified early on in human thought: objective time, the time of the stars, the Sun and the Earth, the Newtonian time of the outer physical world; and subjective time, the inner time of the human experience, the time of society, the time of history. The concept of time in physics is remote and abstract; time is detached from events and processes like the motion of heavenly bodies, the vibrations of molecules in an atomic clock or the human heartbeat. The second meaning of time is intimately connected with what is going on in a system.

The physical notion of time has been connected with heavenly bodies from very early in history. The cycles of day and night, the lunar month and the yearly seasons fix the temporal rhythm of life. The sequence of time is permanent and never changed. It challenges the powers that be by its eternal and invariant nature. It is the time of God and fate. Newton eloquently described the concept of time when he laid the foundations of mechanics:

> Absolute, true, and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year [135].

Einstein's theory of relativity added to the understanding of the nature of time and showed that the Newtonian concept of time needed to be expanded. In special relativity, time runs differently in systems moving relative to each other. But time is still independent of the development of the systems, as they move relative to each other without acceleration, and hence interaction. This concept is reminiscent of Aristotle's definition of time: 'Time is the number of motion'. However, in general relativity, the passage of time does change within evolving and gravitating massive bodies.

The idea of an inner, systemic sense of time has been developed in other areas of physics, and is now gaining acceptance after Ilia Prigogine's seminal work on the self-organization of complex dissipative structures. In open and evolving systems, a sense of the direction of time, the 'arrow of time', has to be introduced [144]. The direction of time is the result of an open system's complexity. These systems are far from equilibrium and have many degrees of freedom and changes in growth and development are irreversible. That is why complex and evolving systems are fundamentally different from simple and reversible mechanical and electromagnetic systems or atomic devices that the reversible laws of Newtonian mechanics, Maxwellian electrodynamics and quantum mechanics describe. In these cases, all elementary processes are, in principle, reversible and therefore have no inherent sense of direction in time.

In global population dynamics, the main equation for systemic growth — the rate is proportional to the square of the total population — is irreversible and this should be expected for a phenomenological theory of an open and evolving complex system. Finally, the connection between the concept of time in history and the temporal structure of the large scale features of the humanity's development provides an opportunity to understand the meaning of time for the global population system and the perception of time suggested by historians.

In their detailed discussion on the perception of time, *History and Time: In Search of the Past*, Savel'eva and Poletaev reference 1,500 publications including ancient Greek texts [98]. The authors identify two senses of time: Time-1, the time of physics; and Time-2, the time of history, expressed by the duration of development. If Time-1 is external, continuous and reversible, then Time-2 is internal, discrete and irreversible. This fundamental distinction is based on an understanding that historians and philosophers have gradually worked towards.

The meaning of irreversibility was best expressed by a dictum of ancient Greek philosopher Heraclitus: 'you can't step into the same river twice'. In the case of the demographic system, the development of humanity manifests the flow of time as a continuously growing number of people. Time-2 is the internal and socially relevant sense of time marked by the duration of major cycles. Time-2 is clearly seen on a logarithmic scale, where humanity's growth becomes uniform (Table 5.3). In regard to humanity's history and the development of the global population system, Time-2 is the natural logarithm of Time-1, which makes it an objective interpretation of Time-2. Franz-Josef Radermacher rightly suggested the term 'Eigen-time' to describe the inner time of systemic growth.

The dynamic understanding of historic time as an extension of temporal duration can be linked to the concept of the *longue durée*, indicating the significance of the relative duration of large-scale events in history. This idea was introduced by a group of French historians who were associated with the journal *Annales: Economies, socieétéés, civilizations* and were largely responsible for developing the structuralist approach to history in the 30s and 40s.

The ideas of the *New Science of History*, pioneered by Lucien Febvre and Marc Bloch, were then ably propagated by Braudel in his studies of global history [91]. On the scale of global history, the features of total history and the identification of structures are the focus of this research. At this scale, a dynamic and historically significant understanding of time is relevant. For example, in his book on the demographic transition, Chenais refers, right from the beginning, to the sense of *longue durée*. Mikhail Bakhtin, a Russian cultural historian, also refers to this sense when defining 'the larger sense of time'.

Epoch **B** is the greatest temporal structure in mankind's development. Once again, the connection between an abstract mathematical concept and ideas developed in historical studies can be traced, establishing a fundamental and fascinating correspondence with historical and cultural structuralism. Structuralism, as a method, was developed by French anthropologist Claude Levi-Strauss, and now it can be expressed in terms of the self-organization of development. The next step is to interpret the whole hierarchy of structures in time and populations in terms of the relative change in the scale of time, determined by the growth of human numbers. The logarithmic transformation of time (Table 5.3) corresponds to the way historians describe cultural anthropology and serves as an objective chart of the past.

The different interpretations of time should be kept in mind when comparing the rate of biological evolution, principally happening in Time-1 (or by another sense of time determined by the process of evolution itself) and social, systemic evolution, proceeding in Time-2. Human evolutionary development is further slowed because the duration of a generation is an order of magnitude longer than for animals of a similar size. Since the arrival of *Homo sapiens*, if not earlier, there has been practically no time for any biological evolution and all changes are really those of an accelerating rate of social development.

Table 5.4. Time as discussed by philosophers

Time-1	Time-2
1. Kinematic	Dynamic
2. Homogenous	Inhomogenous
3. External and independent	Internal and dependent
4. Reversible and causally neutral	Irreversible and causally effective

The main features of the understanding of time worked out by philosophers are summed up in Table 5.4 beginning with the difference between Time-1 and Time-2. This was already recognized by St. Augustine of Hippo, the great thinker of Christian antiquity, who lived in the 4th century. The table is based on a similar one in *The History and Time: In Search of the Past* taking into account and amending some misunderstanding, which arises between ideas of natural scientists and those of modern philosophers on the heterogeneity of time and its discrete nature. French philosopher Henri Bergson originally introduced these ideas when discussing the nature of time and the concept of duration.

In some cases, we probably owe our lack of understanding to an unrestricted usage of terms, taken from exact science, having given them a meaning well beyond what is customary. For example, homogenous and heterogeneous may be both qualitative and quantitative. The discrete in mathematics is definitely coupled to the discontinuous, and to oppose mathematical and dynamic continuity is difficult to comprehend. For a student of science, this lack of understanding indicates a certain deficiency in training or lapses in definitions. It seems that these writers allude to well established terms as images, evoking associations, distant analogies and metaphors that might be in place in literature or poetry, rather than in a learned discussion of complex matters.

In all fairness, it should be noted that modern physics on a number of occasions has used common words well out of their usual context and when these words lost their original meaning. Difficulties had already arisen with the concept of relativity. In high energy particle physics, the words 'barn', 'color', 'strangeness', 'charm', 'top' and 'bottom' for 'quarks' have been introduced as technical terms, describing remote and abstract concepts. In fact, it is not easy to understand what James Joyce meant by a 'quark'. In this new context, these words acquire a well-defined meaning, although, aside from far-fetched and subjective connections, the meaning has nothing to do with these words' common usage.

A fascinating and provocative discussion of the misunderstanding and lack of communication between physicists and philosophers is given by Jean Bricmont and Alan Sokal in *Intellectual Impostors: Post-Modern Philosophers' Abuse of Science* [160]. They ridicule, if not debunk, the inconsistencies of texts by several post-modernist philosophers from the point of view of natural scientists. For an outside observer, many of these writings can be at best described as 'aesthetic irrationalism', compounded by extreme complexity and opacity of style.

Could the appearance of the post-modernist style of discourse be a symptom, signaling the critical time of deconstruction in human development through which we are now passing? If so, the reason for this crisis of rationality may be very real indeed and is, to a certain extent, the subject of this study. During the demographic revolution, when traditions in art and in the language of thought are disrupted there is no time to properly establish them.

It may be suggested that on this occasion philosophers and natural scientists are really speaking different languages, with words that have different meanings. In this case, a common understanding is hardly possible. Newton, prefacing his definition of time, wrote:

> Hitherto I have laid down the definitions of such words as are less known, and explained the sense in which I would have them to be understood in the following discourse. I do not define time, space, place and motion, as being well known to all. Only I must observe that the vulgar conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which, it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common [135].

When words have different meanings, there is no chance for a dialogue or any meaningful contact because there is no common ground for discourse. This certainly shows the obstacles in reaching an interdisciplinary understanding and uniting different parts of knowledge at a time of growing divisive forces in modern culture. I raise these issues to show the difficulties facing us in attempts to bridge what C.P. Snow calls, 'the divide of the Two Cultures'. The difference is really much deeper because even the concept of time may have a fundamentally distinct sense in the humanities, where social scientists, in a way of their own, have worked out its broader evolutionary and dynamic meaning.

Chapter 6

The Global Interaction

Knowledge itself is power.
Francis Bacon

6.1. The Nature of the Interaction

Quadratic growth, large-scale periodicity and synchronism in the development of the global population system raise the issue of the interaction responsible for development. The theory of global population growth provides unequivocal and strong evidence of the existence of an agent acting globally, a collective interaction encompassing mankind. In acknowledging the synchronism of major cycles, history provides a sequence of the most prominent features of the past, although historians are usually reluctant to discuss the deeper reasons for such phenomena. These mechanisms are usually taken for granted. Nevertheless, Wagemann postulated the presence of such an agent without discussing its origin or nature.

In the preliminary discussion, it was mentioned that an exchange of information is responsible for this interaction. In this chapter, the idea will be expanded and developed to take into account the features in human history raised in the previous chapters. An exchange of information is not the sole factor responsible for the interaction because, alone, information — even knowledge — is passive and does not lead to growth and development. Information can only become part of economic development and contribute to growth if it interacts with and enters into the process of self-organisation in a complex social system. But the interaction depends on information, its capacity to influence the behavior of an individual member of a community and societal processes in the knowledge society.

It can be conjectured that consciousness is the agent that is responsible for development and connected with the function of the mind. The concept of consciousness has to be expanded to the larger organizational and productive functions of society. Human consciousness is an individual and a collective phenomenon. The term ‘conscious’ comes from the Latin *consciere*, which indicates that it is an experience shared with others e.g., knowledge and science. The idea that consciousness is not only an individual, but a collective phenomenon has been discussed in detail in psychology. Over the last few decades in Santiago, Humberto Maturano and Francisco Varela developed an approach to interpret consciousness in these terms [20, 21]. In most of these studies, the object was to discuss the nature of an individual’s (primary) consciousness, and then to move to the more complex and difficult issue of social (secondary) consciousness. Social consciousness, although poorly defined as a concept, is widely used and has a generally recognized meaning that may help to interpret the cooperative behavior of humanity. German sociologist Niclas Luhman discusses this issue:

> In this sense any communication is connected with consciousness. Without consciousness communication is impossible. But consciousness is not the ‘subject’ of communication, and — in any other way — the ‘conductor’ of communication. That is why we also shall have to drop the classical metaphor, describing communication as the ‘transfer’ of the semantic content from one psychological system that has it, to another. It is not the human beings that are communicating, but rather the communication itself. Communication forms an emergent reality *sui generis*. The system of consciousness, just as the system of communication (and, on the other hand, in their own right — the brain, cells etc.) operationally is closed systems, which cannot really interact with one and other. There is no communication from consciousness to consciousness, just as there is no communication between an individual and society. Any sufficiently precise definition of communication has to exclude such possibilities (just to imagine society as a collective spiritual state). Only consciousness may think (but in no case can it transpose its thoughts to another consciousness to think beyond itself), and only society may communicate and be the seat of

> communication. In both cases we are speaking of the operations of an operationally closed and structurally determined system.
>
> To understand how the existing, regular and necessary connection between consciousness and communication works one has to introduce the concept of structural connection. Structural connection operates all the time and is inconspicuous, it is there when and just when no one thinks or speaks of it [37].

One of the main goals of interpreting consciousness is to trace its connections to language. While this may not necessarily lead to an understanding of consciousness, it can open an approach that places great importance on the capacity to verbally communicate, speak, exchange information, form ideas and images and develop the capability of thought. In other words, it can lead to the view that consciousness is a function of the mind and that language is the main instrument of thought and the manifestation of reason. The function of language and its connection to consciousness is the way information is processed and transferred. Jean-Jacque Rousseau defined the human being 'an animal that speaks'. The development of these ideas led to semiotics, the study of signs and information transfer.

Information is transferred in two directions. External information is absorbed and processed by each individual. This type of information is based on observations of the outside world and information received from other people. Information is also transferred interpersonally and to society at large. In both cases, a person's subjective concepts and feelings have an effect on the system. As a result of these interactions, information is stored and processed and the state of both systems evolves. Information in a complex social system causes development to contribute to self-organisation and common action. Directed inwards, information leads to the development of consciousness and self-awareness and to an image of the outer world that contributes to the inner world of an individual and, finally, is expressed in the human personality.

The same process goes on in a community, a human subsystem and humanity, which are all coupled by this universal interactive exchange. This continuous and incessant process, which occurs even when dreaming, is the essence of the human condition. Through information — images and thoughts, concepts and ideas, and scientific discoveries and inventions — from our collective memory, experience, and cultural and social inheritance, everyone is conscious of the past and at the same time coupled to current developments. This leads to collective patterns of action and individual behavior. In society, behavior is not the result of an averaging process, but the outcome of this more complex systemic cooperative interaction. The interaction rapidly grows with the number of people and leads to collective patterns of action.

This description, while a gross generalisation, should be taken into account when dealing with interactions at different levels in the global system. At each level, there are complex systems that are, to a certain extent, separated. At the same time, they interact and contribute to the complexity of the whole. These structural levels of complexity can only arise when the complexity of the human mind reaches a certain point. In evolutionary terms, this is the threshold (the qualitative limit) that separates humans from all other creatures. Although at a lower levels there are some organisation and structures (e.g., packs and herds of animals, flocks of birds, schools of fish and swarms of bees). These, however, do not reach the next stage of complexity and flexibility in long-term behavior. Humanity took a decisive step in its social transformation at the beginning of the Paleolithic — the arrival of the tool-making man and the simultaneous early development of speech and then language.

An important step in social evolution was mastering fire when human beings gained access to external sources of heat and no other animal has this capacity. In his informative and fascinating book, *Fire and Civilization*, Dutch sociologist Johan Goudsblom discusses the domestication of fire as a cultural phenomenon [26]. Once fire was mastered a million years ago, long before *Homo sapiens*, the technological and information society was born.

Cave drawings are remarkable evidence of the common human experience that spans many millennia. While visiting the Altamira cave in northern Spain, I had to lie on the muddy floor to get a better view of the artfully crafted images on the cave's uneven walls and ceiling. The pictures were first discovered by a little girl a century and a half ago. Her father, a postmaster, went to great lengths to prove that these drawings were not a recent artefact, but the real thing, now known to be 20,000 years old. Even older cave drawings were recently discovered in the huge Chauvet cave in southern France. Many of these were drawn at least 30,000 years ago [31]. Today, these exquisite and detailed drawings of animals long extinct are amazing. The drawings are evidence of the unity of human culture and direct links to the world of hunters and beasts, and the time of shamans, magic and polytheistic beliefs in the Middle Paleolithic [32].

As the global population grew, the development of human consciousness acquired different forms. It adapted to the evolving demands of society and showed how remarkably plastic the capability of the human mind is. The life of a child from the primitive Guyakils tribe illustrates the influence of the environment and cultural interactions. The tribe, with a very limited language, was discovered in 1938 by a French expedition in the jungles of Paraguay. A two-year old girl, left by the tribe as it fled into the jungle, was picked up by the ethnographers and brought to Paris. In 20 years, she had become an educated member of society: a trilingual ethnographer. Wolf-children who are left in the wild as babies completely lose the capacity to speak and even to walk on two legs [21]. These stories show how the environment impacts the mind and body from a very early age.

After introducing the universal global interaction, the first steps towards gaining some insight into its nature can be made. I am hopeful that this could lead to a new synthesis of the main features of human society and the factors determining growth. The concept of consciousness and its connections to the software of culture as manifestation of collective phenomena — knowledge, customs, art, religion, science, technology and medicine — are yet to be described in more general terms. Throughout history, the contribution and role of each of these components changed.

At the same time, progress was made in the technology of communication. From the first elements of speech and language to writing in hieroglyphics and linear script, to the invention of printing and now the computer, information has grown in importance. A measure of information's importance is the part of the human life taken up by learning. In fact, the effort expended on the information industry is presently larger than the effort devoted to manufacturing and the production of energy and food. The information industry involves more and more time and brainpower. That is why the future of humanity is so often described as an information society, despite the fact that the information society began ages ago.

A decisive factor and key element of the information society is the system of education. Now almost a third of the human life span is devoted to all forms of learning and the education industry and science are becoming a substantial sector of the economy. Since the beginning of humanity, the transfer of knowledge and information is what made man different from all other animals. Now the transfer of knowledge has superseded all other trends in development, as the information-moderated society of the past evolves into the information-dominated knowledge society of the future.

In the last centuries, science and technology became the most significant contributor to human development. Russian geologist and geochemist Vladimir Vernadsky recognized this in his discussion of the place of consciousness and reason in nature. He argued that scientific knowledge has become a global phenomenon that determines growth and development and now it has a global impact on the planet. Vernadsky developed the concept of the noosphere, the realm of reason, and expounded these ideas in his last papers in 1944. Pierre Teilhard de Chardin, a French Catholic priest and well-known anthropologist, shared these ideas and described them in the remarkable book, *The Phenomenon of Man*, posthumously published in 1954 [19]. With great foresight, he develops the idea of complexity and self-organisation in his discussion of consciousness being the essence of the human condition. Julian Huxley's striking remark in introducing the book summarises: 'man is nothing else than evolution become conscious of itself.'

In *The Web of Life: A New Synthesis of Mind and Matter,* Fritjof Capra applied the principles of synergetics to the problem of the complexity of consciousness in an attempt to interpret consciousness with the ideas of non-linear interactions, leading to self-organisation in complex systems [33]. A similar set of ideas on the collective and cooperative interaction responsible for the growth of humanity were arrived at in this study using a consistent non-linear theory of human population growth rather than the intuitive qualitative descriptions that gradually developed in philosophy, history and psychology.

The collective interaction which encompasses everyone not isolated from the main part of humanity, is described by the mathematical model and expressed by the equation for growth. This corresponds to the basic formula for collective interactions that are found in different fields of physics dealing with many-particle systems. In the case of the global population system, it may be seen as the interaction of groups of people, acting coherently with an effective group size on the order of a hundred thousand, of $K = 62{,}000$. At the next level, K groups interact to produce the global interaction. In other words, we have to see the whole phenomenon as interacting networks, and the quadratic term as a measure of its complexity, connections in the network and its constituent elements.

The interaction of pairs should not be seen as the coupling of all boys with all girls because this theory is a phenomenological description of an overall and multidimensional interaction that involves most of what is going on in humanity. The reproductive process is only a part of what is happening and, if it involves family pairs, that is only due to the bisexual nature of human procreation. If people were like amoebae and multiplied by fission, which some may consider rather dull, the same process of self-organization could also take place. In the framework of modern evolutionary theory, the origin of the bisexual mode of multiplication arose out of the necessity to have access to a larger gene pool than a single organism that multiplies by fission has. The larger pool of genetic information is needed for the stability of a species and its adaptive evolution. Similarly, the reservoir of information — cultural or hereditary — in society is not seated in a single member, but rather in a population of interacting

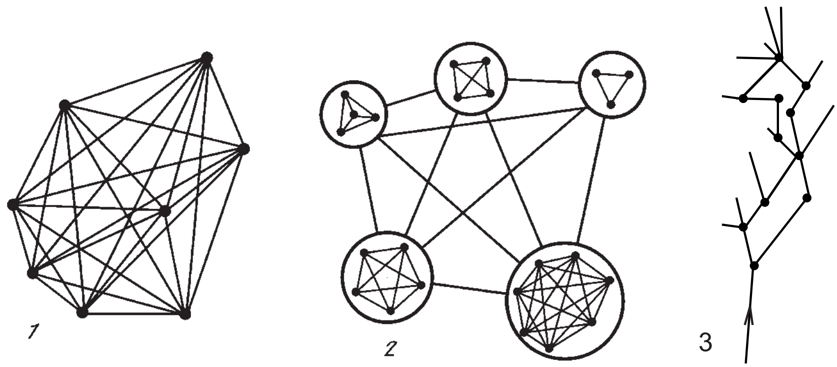


Figure 6.1. Interaction of people in a community

Interaction in aggregated groups – (1), leading to a global interaction – (2), multiplication and spreading of information in a chain reaction – (3)

individuals. In the case of human social evolution, information is transferred culturally by the collective interaction that involves a population subsystem that may act as a pool of cultural information or *memes* — cultural genes suggested by Dawkins.

The 45-year estimate of time for the multiplication of man is set by an information based process of educating the next generation rather than the rate of procreation. The process of educating the next generation is what limits the growth rate. The population growth rate simply cannot increase any more to keep up with the long established dynamic pattern of self-similar growth. This systemic crisis at the population blow-up means mankind has reached the limit in the amount of time spent on bringing up, educating and training the next generation. Development cannot continue in the same way and therefore there will be a revolutionary transition to a new mode of growth. This trend is also expressed in the rapid expansion of education in the modern world and the extraordinary worldwide multiplication of information technologies. While a veritable blow-up, even this cannot maintain the former rate of global population growth.

Recently much is done to explain consciousness on a neurophysiological and molecular biological level. But it is also necessary to interpret consciousness at the higher phenomenological level of interacting and evolving networks, as a manifestation of the systemic functions of the mind and at the global level of self-organised mankind. The model does not contradict and is consistent with most of the available data. Interpreting the interaction in terms of consciousness, however, is at best a conjecture. It is a string of arguments that may lead to a new way to understand human nature. In closing this discussion, *The Oxford Companion to the Mind* defines consciousness as: 'the most obvious and most mysterious feature of our mind' [23]. A special issue of *Scientific American* on the mysteries of the mind and the puzzle of conscious experience is devoted to the latest developments in this rapidly developing and exiting field [36].

6.2. Isolated Communities

Isolated communities show how important it is for societies to be connected to the global system. Given the systemic process of global population growth, any long-term break-up of the global community will lead to a slowing of development in any lesser part of the greater system. Even today, anthropologists discover and study isolated communities that are still in the Neolithic or even the Paleolithic stage of development. In most cases, these communities are indigenous. According to modern ethnographic data, indigenous groups and tribes account for approximately 3% of the global population (200 million people) and inhabit about 20% of land. These communities are special because of their isolation from mainstream global civilization and not because they are indigenous.

The nature of these communities' isolation can be different. Communities can be isolated geographically like communities isolated from Eurasia. Climate can also lead to isolated communities in the far north or in some equatorial regions. Cultural factors like religion or language can also isolate communities. While immigrant communities are not isolated from the global population system, their language develops independently from the language of their homeland. In most cases, prolonged isolation leads to stagnant societies that have low or even negative population growth. The threshold for sustainability is on the order of a few thousand and smaller isolated groups have little hope to survive in an age of globalization.

The western hemisphere was initially populated some 40,000 years ago, when the sea level was 100–120 metres lower than it is today (Fig. 4.4). At that time, the climate was considerably colder and drier, and northern Europe and North America were covered by a thick continental ice sheet. Over thousands of years, tribes migrated to the Western hemisphere over the land bridge that connected Asia and America. These tribes brought Stone Age technology and culture, including shamanism, with them. As the result of the global warming cycle, the continental ice sheets melted, the climate changed and the sea level rose. The Americas were cut off and, for a long time, the population developed independently from and at a slower rate than the rest of world. By comparing pre-Columbian civilization with the civilization that developed in Eurasia, the common trends in development and the peculiarities of local cultures, due to the long separation of these two societies and geographic regions, can be identified. A dramatic consequence of these differences, ‘the clash of civilizations’, was the decimation of the pre-Columbian American population after the Old World discovered the New World. Migration, wars and devastation are part of the systemic development. Such interactions in the global system are unfortunate, but inevitable, events in growth.

The fate of isolated communities shows information’s significance in development. A connection, even weak, with the world system is an essential resource for development. Many isolated communities were located in places with a congenial climate and enough land and natural resources, but retained small populations because informational isolation inevitably holds up growth, social evolution and technological development.

A characteristic symptom of long-term isolation is that communities become stationary and frozen in development. Growth and development are systemically linked and therefore isolated communities are literal time machines. Archaeologists and cultural anthropologists study these communities to discover the basic features of early human societies.

The isolation of communities is not only relevant for distant cultures. Given the change in the scale of time and development, the effective time of isolation gets shorter and shorter as the demographic transition is approached. If in the Paleolithic separation was for many tens of thousands of years, a recent effective cut-off can be much shorter. For example, in the 1850's after the fall of the Tokugava shogunate, which secluded Japan from the world in 1603, and the Meiji restoration, Japan opened up and, recognising its condition, did much to make up for time lost.

The partial isolation of the Soviet Union from 1930 to 1990 led to its loss of contact and retarded its growth in critical decades, when the global community rapidly approached and passed through the demographic transition. The global acceleration of growth during that time could have mattered more than Japan's 250 years of isolation. However, isolation is a complex phenomenon. It can lead to certain positive trends such as the remnants of feudal structure and work ethic in Japan or the education system in Russia. These relics of bygone ages have become valuable assets from the past.

The current intense and rapid processes of globalization make it difficult for isolated communities to continue their existence. The global communication network, travel and commerce have drastically changed the world. It is becoming increasingly unlikely that any community can stay isolated. At the same time, perhaps as a reaction to global trends, a new type of isolation is appearing. Groups of people, based on ethnicity, religion or language, tend to preserve and cultivate their identity and oppose powerful unifying forces. Not accounted for by the theory, these processes of group identification show how isolation and segregation operate and how forces of local cultural identity work and sustain the integrity of isolated communities.

6.3. Hierarchy of Demographic Structures

Although the emergence of structures is apparent in the theory, large-scale temporal structures can be identified in the pattern of global population growth and be substantiated by historical and anthropological data. With the additional insight from an understanding of the nature of the global interaction, more can be said about the nature of complexity of the human system as the hierarchy and sequence of structures are identified both in time, space and population size.

The lowest structure is a human being, followed by the family, with essential ties of kinship. At this level, the number in a stable and sustainable group is approximately 100–150. This unit appeared very early and Coppens referred to it in estimates of the size of the *Homo habilis* population. The next structural level is the subsystem that each individual can personally interact with. These include subsystems like tribes and counties that later can be identified, in terms of information exchange by a common dialect. On this level, the size of the group is approximately on the order of $K \gg 100{,}000$. This is the scale of a township or an administrative district in a larger megalopolis, units recognized by city planners and sociologists.

Languages identify the next level of self-organisation. Linguists estimate that there are 5,000–10,000 languages in the world. The discrepancies are mostly due to how dialect is defined. In all cases, however, these distributions change with time and should be seen as the result of self-organisation, as generalised information leads to socially relevant linguistic structures and subsystems. The extent to which the global population system is interconnected and behaves as a system depends on history and the time scale of phenomena.

6.4. Globalization and Development

The highest level, humanity, includes all interactions and migrations. At this level, intermediate subsystems mix and merge, which leads to a global state of self-organisation that is now passing through its final stages of globalization. This state fully recognizes its new identity and interacts and contributes to the complexity of the whole. These structural levels of complexity can only be reached when the complexity of the human mind attains a certain critical level. At this level, global population growth and development the result of the interaction is global and universal.

In a stabilized global population, the function of the global interaction has to change because there is no longer a connection between numerical growth and development. The change in the paradigm of growth and development will have major consequences for the future and will be determined by the new function of the global interaction. At present a new group is emerging: the global population system with a magnitude of K^2. The processes loosely defined as globalization determine how this new structure will be identified and evolve. Globalization may lead to a new and decisive step in the economic, social and cultural long-term evolution of global society.

The hierarchy of structures is a result of the global interaction's non-linearity. All relevant dates and numbers are expressed as functions of K, the universal constant that determines all proportions and relations in the global population system. Most of these results follow directly from the model, while others, including inner variables, are the result of plausible inferences and can be substantiated by the development of the theory. In the first place, they are the spatial variables and hidden dynamic variables, asymptotically averaged in the initial equation of growth. The presence of these structures in complex systems is the result of the subtle interactions of the many factors contributing to self-organisation, rather than the result of a single, well-defined process.

At a bifurcation, further development is initially poorly defined and chaotic. The instability first leads to the emergence of subsystems that gradually identify themselves. Then a new structure is established within the system. This occurred during Epoch **B** when the demographic cycles appeared. The final transition to stabilized growth in Epoch **C** is the result of the major instability of the population explosion that leads to a stabilized global population. In many cases involving social phenomena where the complexity — in the common usage of the word — and lack of quantifiable data preclude the construction of meaningful models, it would still be possible to use the results and ideas coming from mathematical models for a qualitative analysis. The ideas and analogies that can be found through systems dynamics — both linear and non-linear — should be known and sensibly used in expanding the analytical instruments now available for studies in social sciences.

6.5. Socioeconomic Cycles of Development

In conclusion, let us consider the meaning of the cycles observed by historians and economists. For many this has become quite an obsession and even a fad because cycles of very diverse nature, such as periodic changes in the length of skirts, are often mentioned. One feature that is common to all cycles is that their linear or non-linear oscillations are limited.

The boom and bust investment cycles were discussed in economic theory at the end of the 19th century. Russian economist Nicolai Kondratieff was probably the first to identify more complex socioeconomic cycles. In this case, first innovation and then investment and social development are all coupled together and generate a cyclic pattern of development. These cycles have proven to be useful in discussing major features of growth and development and forecasting social and economic trends. If these cycles, with a period of 50–55 years, are traced sufficiently back into the past, then the expansion of time should be taken into account. This avenue of study, however, has not been taken [100, 102].

The periodicity of demographic cycles is best seen throughout history on a logarithmic scale. The technological and social identifiers and the way they spread worldwide make these demographic cycles similar to the business socioeconomic cycles. They are the result of many, if not all, factors that contribute to growth and are a significant feature of a meta-historical approach. Since these global transitions are observed synchronously on a time scale that encompasses the human story, the simultaneity of major periods in global history has been extensively discussed by anthropologists, historians and economists. In fact, the worldwide synchronism of these cycles is a strong argument in favour of, if not a proof for treating the human system as a global entity.

The existence of cycles of different nature and scale in time or space indicates that the system is stable. Otherwise these cycles would not be observable. Nevertheless, the diversity of the cycles shows that elements of dynamic chaos are present. This makes short-term and local predictions for the population system and society difficult. Only long-term demographic cycles have a regular pattern, although even in these cases they are only indirectly identified by the gross features of development.

The presence of different cycles during historical development and the lesser cycles' chaotic character raise an old problem that has vexed generations of historians: 'Is there progress in history?' This question is isomorphic to the one posed by Lewis Fry Richardson: 'Does the wind possess a velocity?' This led Russian mathematician Andrey Kolmogoroff to the concept of self-similarity of turbulent motion and Benoit Mandelbrot to a discussion of the fractal geometry of turbulence [142]. Locally and temporally, weather is chaotic and, in the long run, unpredictable. Nevertheless, the general and overall motion of the atmosphere, which determines the pattern of the seasonal changes and climate, is regular and deterministic and has gross features that are predictable. Chaos rules for all lesser scale disturbances. In society a single human being is largely independent of the greater design. He acts according to his own will and can only become historically significant when his policies match and amplify inherent trends. Much in the same way, the growth of human numbers is stable and predictable on a global scale. Increasing by five orders of magnitude, population growth follows statistical laws and is determined by summary factors that cannot be found among those individually identified in history.

In studies of history, a multitude of factors have been taken up by different historians as decisive:

> The ideas of world history are just as numerous as the interests of the historians. Some are mainly interested in culture (Forster, Spengler), others take up religion (St. Augustine, Toynbee), or the

> state (Ieronimus, Hegel), or the political structure of society (Plato, Vico), the fifth takes up a national idea (Hegel, Danilevskii), the sixth takes up economics (Smith, List), the seventh — technology (Jaspers, Toefler), and so on. Another common feature of all 'world histories' is that they are euro-centric. [98]

This list shows the complexity of history and the multitude of factors contributing to growth. They are all coupled, interact and contribute to development, which is described by the global non-linear collective interaction. This interaction is operating by the propagation and multiplication of input from these factors without going into the substance of their content, as each message is mixed up in the totality of the process of interactive development. Then the output of the phenomenological interaction can be interpreted in terms of history, seen from different aspects by historians, when the non-linear interaction in a way of its own produces a synthesis of these factors describing global history.

Given the many factors interacting in the global population system, it is obvious that any formal description of the system that could lead to a representation of its dynamics in aggregated, but partial, variables is practically impossible. The facts of history have to fit into the pattern of global development, although they cannot fully explain it. This is why reductionist modeling does not work. To describe global growth, one has to introduce an interaction that cannot be simplistically reduced to elementary historical or sociological processes. Only when these processes are averaged out and treated statistically, can an understanding of the factors of development be expected. That is done when the universal global interaction is brought in.

Chapter 7

The Demographic Transition

Blessed be those who visited this world at decisive times!
F.I. Tyutchev

7.1. Nature of the Demographic Transition

The demographic transition is usually defined as a change in the state of the reproduction of a population [72]. French demographer Landry studied the decline of France's population growth rate and discovered the fundamental nature of the transition phenomenon designating it as the 'demographic revolution'. In 1945, American demographer F.W. Notestein suggested the term 'demographic transition'. The concept of the demographic transition has developed into a systematic theory in modern demography that describes the complex processes that accompany the transition. *The Demographic Transition: Stages, Patterns and Economic Implications* by French scientist Jean-Claude Chesnais is a recent in-depth review of the subject [64].

While it is unsurprising that France was the first country where the growth and subsequent decrease of the population growth rate was discovered, the demographic revolution is difficult to discern by an analysis of the primary demographic data (Fig.2.3). In *Traite de Demographie,* Landry explains:

> In the eighteenth century France experienced its great political revolution, which erupted in 1789; but one should also speak of a demographic revolution. The political revolution was marked by sensational events, like the storming of the Bastille or the abolition of privileges; within a few years it reversed or supplanted many things. There was nothing sensational to mark the other revolution. Its progress was inconspicuous and relatively slow. Nonetheless, it still fully qualifies as a revolution, since where there is a change of regime there is a revolution — and this applies to the demographic

> field as much as to any other. Abruptness of change is not a prerequisite. Indeed, speaking of a demographic revolution in which limited procreation replaced unlimited, there is every reason to adhere to this definition without adding anything more [49].

During the transition, death and birth rates change rapidly (Fig 7.1). According to the demographic transition theory, the changes begin with an initial decrease in the death rate at T_a [64]. The consequent fall in the birth rate begins later at T_b and is accompanied by economic development, an increase in living standards and the consequent development of health services. The growth rate passes through its maximum because of the interaction of these two factors, which are shifted in time by a time interval close to t Later, the growth rate gradually approaches zero as the population stabilizes at T_w when the decrease in birth and death rates approach the same limit after the transition. Migration may change the ideal description for a specific country.

The sequence of events shows that the change is rapid and that the population is never at a state of relative equilibrium. In fact, it is a non-equilibrium transition. It is a shock that could not happen faster given the duration of the transition is the microscopic time of the system. Therefore, it is impossible to describe the transition in linear terms. Because of the transition, the population stops growing and there is a marked change in the population's age distribution. The change in the age distribution is the last in the sequence of events and is a significant societal transformation. It is only possible to describe the complex nature of these processes in terms of a systemic approach and by treating the whole phenomenon as a non-linear transition. The transition as a rapid, non-adiabatic change in the state of a population system is similar to a strong shockwave in a gas, an atmospheric front and other non-linear phenomena that are extensively studied in the physics of fluids and many-particle systems.

It is now well established that every country will pass through a demographic transition and have its population stabilize. The changes in the relative growth rate for different countries as they pass through the transition are shown in Figure 3.4, which is based on a similar diagram by Chesnais. Initially, all of the curves

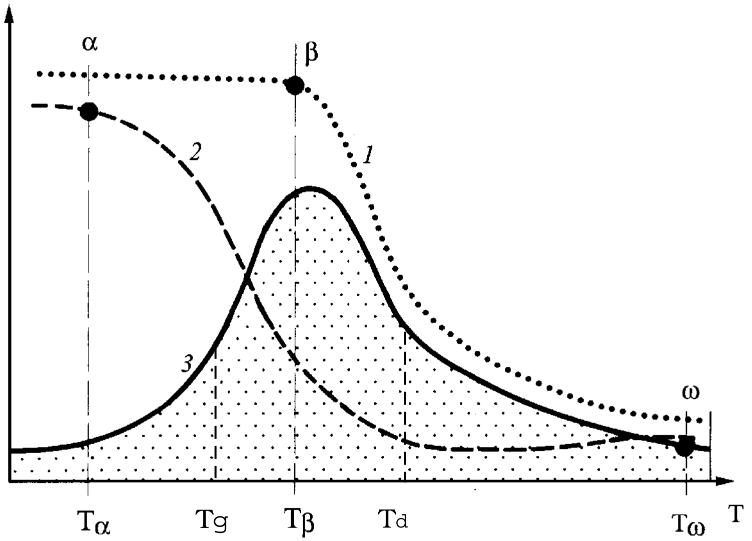


Figure 7.1. Stages of the demographic transition

1 — birth rate, 2 — death rate, 3 — growth rate

were shifted to a common origin in time in order to classify transitions in different countries. In Figure 3.4, the curves are shifted as they occur in real time.

Traditionally, most demographers studied the demographic transition in various countries and classified the historic, social and economic conditions as the pattern of growth and procreation changes. These classifications are done to compare and discuss the relevant socio-economic conditions and identify the beginning and end of the transition, rather than to look at the collective dynamics of growth. Clearly, the global nature of the transition is ignored because, if it were taken into account, it would be difficult to identify the causes of the changes in terms of conventional social and economic factors (Fig. 7.2).

In the model, the transitions are shown as they happened in real time in order to demonstrate how transitions in different countries correlate with one another. In the model, the beginning of a specific transition is placed at the point of most rapid increase in the growth rate T_g and the end of the transition is at the point

Table 7.1. Data on the demographic transition [64]

Country	Beginning T_a	End T_b	Duration Years	Demographic multiplier M
France	1785	1970	185	1.62
Sweden	1810	1960	150	3.83
Germany	1876	1965	89	2.11
USSR (Russia)	1895	1965	70	2.05
India	1920	2010	90	3.67
Mexico	1920	2000	80	2.95
China	1930	2000	70	2.46
Egypt	1946	2010	64	3.88
The World	1955	2045	90	3.00

of most rapid decrease in the growth rate T_d. Similar to Chesnais's definition, the duration of the transition, defined in these terms, ranges from 190 to 64 years. France, England and Sweden — the first countries to experience the transition — took the longest time for the transformation to happen. During the 19th century, about 60 million people left Europe. A description of the transition in Sweden is complicated by the fact that half of the population of Sweden emigrated because of a rapid population blow-up.

Chesnais introduced the demographic multiplier as a general characteristic of the intensity of the transition. The multiplier M is the ratio of the population after the transition to the population before the transition. The demographic multipliers for China M = 2.46 and India M = 3.67 are particularly interesting. In these countries, which comprise many regions at different stages of economic and social development, the value of M is close to what is expected globally. In the case of France M = 1.67, the discrepancy is large because the transition came early. In Mexico M = 7, the discrepancy is also large because Mexico has recently become a dynamic country. These special cases (France and Mexico) are inconsequential because of the overall correspondence of modeling and the value of M for China and India, the largest contributors to the world population.

The education of women is usually considered the most important factor that determines the changes during the transition. The development of health services, which leads to a decrease in infant mortality and an increase in the life expectancy, is also significant. These factors, accompanied by rapid economic and urban development, are the main components of demographic policies, which facilitate the development of a country during the transition. The transition involves many processes that happen simultaneously and that are interdependently coupled, which makes it even more difficult to identify the most significant factor that determines the passage through the transition. Nevertheless, education and medicine are probably the most important social factors in the growth and development of each country.

7.2. The Global Transition

In the phenomenological theory, the global demographic transition is seen as an all-encompassing worldwide event. According to the theory, the demographic transition in each country does not happen independently, but occurs as part of a global transformation. By comparing a detailed description of the demographic transition in an individual country with a phenomenological treatment of the global system, it is possible to establish a correspondence between these two levels and describe this critical period in the current development of mankind.

In the Model the global demographic transition begins at $T_g = T_1 - t$ and ends at $T_d = T_1 + t$ and lasts $2t = 90$ years. The calculated value of the global multiplier $M = 3.00$ is universal and independent of $t$and close to Chesnais's value for the global population M=2.95. In the Model, as the result of the transition global population will treble and the population limit of the world $N_¥ = 12$ billion is twice the population at the maximum of the transition at $T_1 = 2000$ (Figs. 7.2 and A2).

Chesnais places the beginning of the demographic transition at the time when the death rate starts to decrease and the end at 2010, not 35 years later, when the population growth rate decreases. The histogram for the global population growth rate describes the overall change in the growth rate and is equal to the difference between the birth rate and death rate. In this case, the transition shifts to a later date without changing shape.

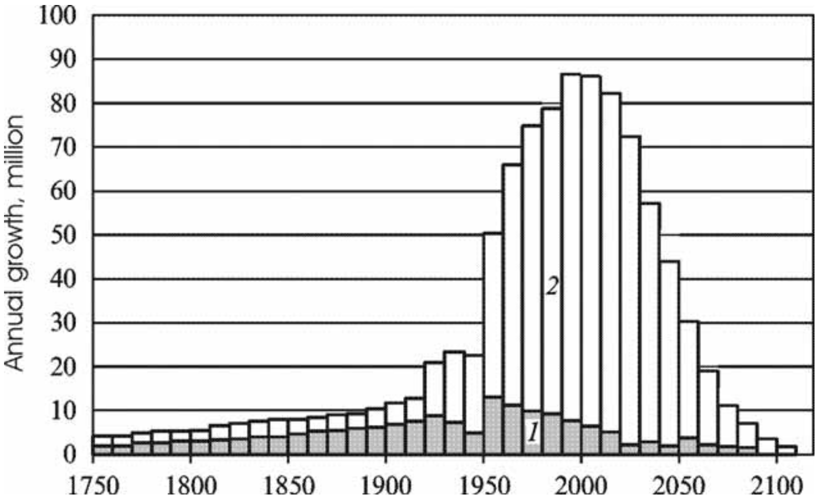


Figure 7.2. World demographic transition 1750 – 2100 [62]

Annual growth averaged over a decade. 1 — developed countries, 2 — developing countries

The global demographic transition takes only 90 years and, during this interval — 1/50,000 of human history — a fundamental change in the mode of the growth of mankind will happen. To imagine how abrupt the transition is, if its beginning is placed on Fig 7.2, a point corresponding to 5 million years ago is about a kilometre off the page. Once again, it is clear that a logarithmic scale is the proper way to present time. A different image of the transition is produced if the number of people who will live through the demographic transition, about 10 billion, is considered. This is only $1/10^{th}$ of the 100 billion people who ever lived. A human being has a one in ten chance of being caught in this singular period of rapid change.

As the global demographic transition develops, the transitions in developing countries get shorter and shorter (Fig. 3.4). The narrowing is the result of the interaction between countries in the global population system. It also takes place in large countries like China and India. These countries, which contain regions at different stages of development, demonstrate the same synchronizing interaction in the collective way they experience the global transition. The narrowing is typical for interactive non-linear dynamic systems and gives substance to the existence of the global interaction, which was introduced to explain global population growth. In the case of the demographic transition, this interaction affects the life and development of billions of people and, in a fundamental and profound way, determines and changes the behavior of the largest communities in the world, which are now passing through a decisive transformation.

It can also be expected that after 2000, the interaction and the narrowing of the transition could lead to a faster decrease in the global population growth rate. The resulting transition will be skewed and this asymmetry is already seen in the transition of the developed countries, which went through it before the bulk of the transition occurred. The asymmetry may also lead to a lowering of the asymptotic limit of the global population in the future. In this case, 12 billion is the upper limit of the ultimate global population and it is better to state the expectant population to be N_{∞} = 12 (+0, –2) billion.

7.3. Processes during the Transition

The transition is remarkably rapid and the outcome of the global transition is a fundamental change in the mode of population growth. In fact, the transition could not be happening any faster. The population will level off at approximately twice the current population. As the transformation will have an effect on many, if not all, features of human life, it is of interest to look into what is happening during this remarkable and singular time. This event, which we have the luck or misfortune to experience, is reminiscent of the Chinese proverb: ‘May you live in interesting times.’

While the global transition technically began in 1955 and will end in 2045, the whole period started in the middle of the 18th century and will end in the 21st century. Most major social revolutions and great cultural development took place during this fateful time of modern history, which can be correlated with the

Table 7.2. The 20th century top engineering marvels («Scientific American», May 2000)

1. Electrification	6. Radio and TV	11. Highways	16. Health technology
2. Automobile	7. Agricultural mechanization	12. Spacecraft	17. Petroleum and gas technology
3. Airplane	8. Computers	13 Internet	18. Laser, fiber optics
4. Water supply distribution	9. Telephone	14. Imaging	19. Nuclear technology
5. Electronics	10. Airconditioning and refrigeration	15.Household appliances	20. Advanced materials

demographic process. It is no accident that the first country to experience the transition was France, where the French Revolution soon took place, as mentioned by Landry. It is instructive to look into the demographic precursors of the revolutions in Russia and China, although this should not be seen as an exercise in a mechanistic interpretation of history.

In the model, no distinction is made between developed and developing countries because both are interacting parts of the same global system. Separating the parts of the global population system at different stages of growth would not only complicate matters, but is conceptually unnecessary because the transition for the developed countries happened earlier and at a slower rate than the transition occurring in the developing world. The global population acts like a global community undergoing a common transformation that involves every part and not like a collection of independent entities. The fact that the transition is happening in every country at practically the same time shows that in terms of the dynamics of the transition, developed and developing countries are not as different as is usually assumed.

The onset of the global demographic transition was accompanied by great historic upheavals, remarkable economic growth and urban development. The vast migration of peasants to towns where they joined industry is a major factor that led to the Industrial Revolution. The Industrial Revolution led to an increase in productivity and to the rapid growth of new industries. This growth was facilitated by an ever-increasing output of energy and the growth of transport, communication, education, and finance.

Most of these developments began in Europe and then spread throughout the world. The majority of the extensive literature on the demographic transition is directed to single out the main factor that determines development like industry, education, medicine, or inventions and scientific discoveries. Nevertheless, humanity is an interacting non-linear system, which makes it difficult, if not impossible, to trace cause-and-effect connections. Unsurprisingly, Chesnais concludes that it is impossible to explain this complex phenomenon in terms of cause and effect (linear modeling) because only an inherently non-linear analysis can describe this transformation.

History of science and technology repeatedly shows that the most important factor is how ready society is for innovation when new developments (the steam engine, the car, the telephone, the radio, the television, the transistor, the machine gun, the airplane, vaccines and antibiotics) are introduced [129]. Many of these inventions existed in a latent state and then, when a demand arose, they sprang into existence and contributed to development in decisive ways. Many inventions are invented by different people at around the same time, leading to endless arguments as to who was first. In the past, most inventions came before science could provide the fundamental understanding. Presently, innovation and engineering developments depend on scientific discoveries as well as the interaction of many different technologies.

As with all complex phenomena, cause and effect are interdependent in cases of technological development. The paradox — which came first, the chicken or the egg? — is resolved when, instead of the linear cause-and-effect connection, a non-linear approach is used and the evolution of life is taken into account.

7.4. Changes in the Age Distribution

The most lasting and profound change due to the demographic transition is the change in the age distribution. Age distribution is usually depicted by a diagram of the composition of a population as it changes with age and sex. During the demographic transition, the pyramid that describes the distribution in a growing population is transformed into a column, which is typical of a population that has stopped growing [58, 63]. The onset of the transition is marked by a rapid increase of a young generation and the final stage is characterised by the predominance of an old population. The change in the age structure will lead to a decrease in the birth rate and the increasing size of the older generation because of longer life expectancy. Both of these factors contribute to the new age structure at the closing stages of the transition. After the transition, it can be expected that urbanisation will result in 3/4 of all people living in towns, although, in the case of an information-based society, urbanisation may not be so extensive.

The period of global change during the population transition will take nearly 350 years (1750–2100) and is much more like a revolution than a transition. It would be best to reserve the term ‘demographic transition’ for the transformation of distinct populations and its demographic aspects. Landry was correct to refer to it as a ‘demographic revolution’ because the term is meant to describe the entire period of the transformation, a complex multidimensional global event. In this case, the global demographic revolution and the consequences of the demographic imperative will become subject for historians, sociologists, economists and anthropologists rather than the responsibility of being solely limited to demographers. By an accident of history, the effective high point of the global demographic revolution is centred at the end of the millennium, ascribing to this singular moment a real, but in no way magical or mystical, meaning.

The effective time of change of the global transition, 45 years, is much shorter than the 70-year life expectancy in developed countries and almost equal to the average human age in the world, 40 years. The rapid non-equilibrium transition leads to the break-up and disruption of traditions and customs, which have, to a great extent, stabilized human societies and set up long-term correlations between generations of an extended family. Today, the connections between generations have been cut and many see this as one of the reasons for the strife and stress of modern life

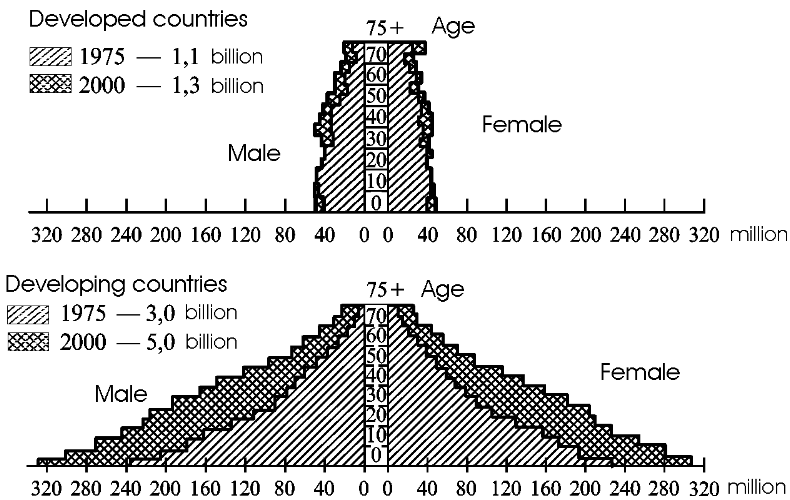


Figure 7.3. Age distribution for the developed and developing world in 1975 and 2000 [74]

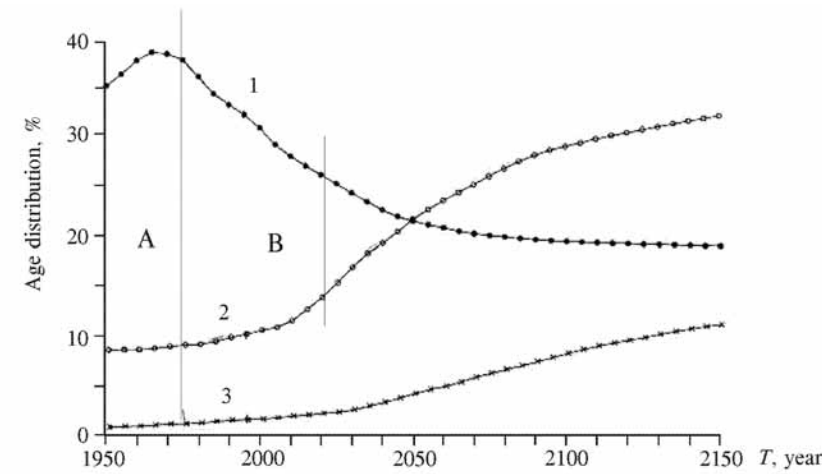


Figure 7.4. Change in age distribution for the global population 1950–2150 [80]

1 — age group less than 14 years, 2 — age group older than 65 years, 3 — age group older than 80 years. A — age distribution in developing countries, and B — age distribution in developed countries in 2000

and a factor that should be attributed to the demographic transition. Francis Fukuyama discusses these aspects of modern life in *The Great Disruption: Human Nature and the Reconstitution of Social Order* [99]. Once again, a sensitive observer of modern life has identified the disruption as a global event, but is somewhat at loss in tracing the origins of this universal state of affairs.

Vishnevsky has indicated that the entire path of self-similar growth and development during Epoch **B** until stabilization can be described as a time of transition to a stationary state of dynamic equilibrium. Its last stages are marked by the explosive instability of the global population blow-up and culminating in the demographic revolution. Humanity will finally reach this asymptotic condition, the state of normal development, after a turbulent transient path marked by great inequities and inequalities.

The process is similar to a theme explored by St. Augustine, Stendhal and Tolstoy: the life of a young man passing through the adventures of a turbulent, wild and violent youth. Then, after gaining experience and wealth, he suddenly marries off and settles down to a peaceful and quiet life, where with hope his life will be guided more by reason rather than instincts.

7.5. Transition and the System's Approach

In his account of the demographic transition, Chesnais concludes:

> In directing our attention to the analysis of long-term growth in large industrial nations, we have focused more particularly on two generally overlooked aspects of this demographic dynamic: rural migration to sectors of high productivity; and, in a more general manner, the direct and indirect implications of mortality declines, according to the various forms they have taken historically. More detailed study of the connections between demographic and economic growth, based on long term time series, would require — as in our treatment of the French case, only in greater detail — separating out the components not only of demographic increase but variations in national product. The components of economic growth (consumption, investment, and foreign trade) could then be con-

nected in their temporal variations to the components of demographic growth. But this is the subject of a more detailed analytical study than the ground-clearing task we have undertaken here [64].

By directly referring to economics, Chesnais is correct to extend the scope of interpretations of the demographic transition. The results of global modeling also have to be reconciled with economics because both basically deal with the same subject, but on different time scales. This was accomplished by broadening the scope of this study and viewing global population growth, no matter how crude an indicator it is, as the sole universal measure of global economic development. This only became possible by going to the global level in aggregating data and expanding its extension in time, as compared to the level of demography, economics and sociology.

The singular importance of this characteristic of growth is emphasised by giving such prominence to the dynamics of population growth. This parameter has been used throughout this discussion to develop a non-contradictory and consistent quantitative systemic theory to describe the gross features of the past and present. Nevertheless, concepts and data from anthropology, history, economics and sociology can add a further dimension to these numbers and provide socially relevant content. The human side of growth and development — wealth and misery — thus enters the analysis.

People customarily use economic and political terms to explain what has happened and what is happening. However, this can only be done if an understanding of the grand design of history is achieved and local and temporal events are reconciled with the dictate of the demographic imperative, which can be reached using a systemic and interdisciplinary method that is based on a quantitative theory of the human population system's growth. In this case, methods from non-linear mechanics and synergetics may help to provide economists, historians and demographers with a new approach to their studies. The new approach provides methods, images and models for analysing and describing the remarkably complex problem of the development of mankind. It also offers a quantitative treatment of humanity's growth and development.

In the treatment of the demographic transition, modeling and demographic methods compliment each other because they overlap when describing this critical period of development. This happens because the time constant of the transition, which is the time of an effective generation, meets local and global treatment. The time constant expresses the overlap of two scales of time and space in the theory. One time is local and limited to a generation.

The other time is global and reduces the details of human life to the time t. As we recede from the critical date of the transition, the time of a generation no longer describes the rate of change; the scale of change becomes the age of the event. The self-similar nature of the global population system's growth has to be regarded in terms of the change in the scale of time, which is similar to the sense of time in the theory of general relativity. In this case, the development of the system determines the scale of time. The introduction of the temporal sense of time, measured by its age, shows the relative nature of time in history. The principal variables — time and the global population — are complimentary variables coupled in a non-linear relationship.

A similar, but more general, approach has to be developed to reconcile modeling with economics. In this case, all economic processes are summarised by a single interaction that is proportional to the square of the global population and that describes an evolving system far from equilibrium. The nature of the quadratic global interaction is the factor that requires a greater degree of understanding. Introduced phenomenologically, the model is operational and certainly serves its purpose, but it has to be developed further. Finally, the mathematics and the formula have the necessary structure and asymptotic behavior. The minimal number of constants should be seen as an asset of the theory and the theory's internal consistency provides a solid foundation for this interpretation. These are the main reasons for the success of the model and why it may aspire to the status of a theory. It provides greater insight into the development of mankind and offers a frame of reference for many of the results and concepts worked out in social sciences.

In the theory, the demographic imperative expresses the dominance of the main variable, the parameter of order, which

Herman Haken proposed in synergetics. The principle indicates that growth is independent of external constraints, which contradicts Malthus's population principle and the subsequent reports to the Club of Rome. Humanity will follow, as it has in the past, the demographic imperative and be dominated by internal factors of growth rather than being immediately limited by any external constraints. These global constraints may become limiting factors in the future. The natural way to take them into account would be to extend the concept of the global population system to include the resources that are limited and leave the unlimited resources beyond the system and the premises of the model.

7.6. Models and Theories of Demographic Processes

A model usually deals with a description of phenomena. It has to serve a rather limited purpose and be useful. Although the model has to be self-contained, it can be contradictory and even inconsistent at its limits. The claims of the theory are greater. The theory, based on a broader conceptual foundation, is supposed to provide insight into the phenomena studied. The initial formula for hyperbolic growth is a model, a useful generalization of empirical data within pragmatic limits. However, when the characteristic time $t$is introduced, the model begins to turn into a theory.

First, the limits of the model became apparent and then new results were worked out, the number of people who have ever lived could be calculated. These results were impossible with the initial model. In fact, meaningful theories have an uncanny property: they lead to new departures for study, which at first seem to be well beyond their initial agenda. This is probably the most incomprehensible and remarkable thing about mathematical theories of phenomena in the physical world.

Every time a hidden message from a theory was unraveled, new results were obtained. This adds to the theory's credibility and is evidence that the theory is sound. The ideas on the nature of time in history, the discovery of the demographic cycles and the possibility of discussing the stability of the demographic process act much as an experimental proof of the theory. Finally, the self-similar nature and the quadratic law of growth have led to the concept of a universal global interaction. In other words, the theory matters more than the model and suggests directions for further work. This is the real meaning and message of the theory. On some occasions, a model's status is inflated and called a theory to give it greater credibility. At present, this devaluation of concepts is rather widespread and is possibly the result of the erosion of values and criteria of intellectual standards. It could be a consequence of the demographic transition itself, when there is no time for a tradition of research to become established.

In the case of the theory of growth a deductive presentation (not to mention axiomatic reasoning) is infeasible and impossible. In most fields of mathematics, a strictly logical edifice may be built. Although it is intellectually appealing when presenting proofs and results, it hardly ever functions as an instrument of research and reasoning in physics. This style of thinking is quite out of place in complexity problems. In the complex world of human affairs, any axiomatic reasoning is futile because the problem is rather poorly defined in descriptive terms, when only demography and economics deal with numbers.

In accessing the credibility of a theory, one should keep in mind Bohr's remark: 'the agreement of a wrong theory with experimental data does not prove the theory to be right'. In other words, apart from matching the observed demographic data with calculated numbers in modeling, a consistent theory has to meet other requirements. These were mentioned while the theory was being developed, but it is worth reiterating them to point out the premises set by the principles of theoretical physics, for these ideas have yet to be taken into account in demographic and social studies.

In a phenomenological theory of the global population system and at this stage of our understanding of the system, its elementary processes are not really necessary for justifying the method. The constancy of growth and development throughout Epoch **B** is based on an assumption that the human capacity for growth is due to the appearance of *Homo sapiens*, if not *Homo habilis* and expressed in the self-similarity of growth ever since. This leads to scaling, which implies the use of power functions and is founded on well-established principles. The collective nature of the universal global interaction, the irreversibility of evolution and growth, is responsible for the essentially non-linear character of quadratic growth. The fundamental interaction, based on the capacity of the human brain and mind, has not really changed throughout history, even though technology, medicine, culture and now science have evolved and contributed in a spectacular way as factors of growth.

After the interaction has been identified, it can be interpreted using ideas and concepts from history and anthropology, sociology and demography. Interpreting the global interaction in terms of consciousness is a conjecture, or rather a hypothesis, that can help in understanding growth and provide a connection to other concepts from social sciences. Nevertheless, all this is essentially unnecessary for developing a formal theory. In that case, a theory can exist independently and even have the promise of further research, although it would be hardly applicable to human affairs, as it ceases to be connected to the ideas and concepts developed in social studies.

An essentially non-linear theory, the model is only applicable to the global population. The theory (or model for that matter) has structure similar to modern cosmology, which is only applicable to the whole Universe. But if the Universe is expanding from the initial singularity of the Big Bang, mankind is now right in the middle of its singularity, the very peculiar time of the demographic transition. The large parameter K is similar to the large numbers in cosmology, expressing the connection between the very small and the very large. These numbers determine all proportions in a theory and connect the microscopic parameters of elementary particles with the macroscopic characteristics of the Universe, vividly described by Martin Rees in *Just Six Numbers. The Deep Forces that Shape the Universe* and also in *Cosmic coincidences. Dark matter, mankind, and anthropic cosmology* [162, 163]. If cosmologists aspire to produce 'a theory of everything', then this theory is working towards a 'theory of everyone'.

Perhaps there is a deeper connection between cosmology and the evolution of man, a connection indicated by those ten cosmologists, who appear when the crude hyperbolic growth curve is extended to the origin of the Universe (Fig.3.5). On a logarithmic scale, ten is close to one. Whether it is a mere accident of numbers or an indication of a connection between the scale of human development and the world at large has been a problem philosophers, cosmologists, physicists and biologists have confronted for ages. This could be a manifestation or the consequence of the anthropic principle, that rather mysterious idea in modern cosmology [149]. Stephen Hawking best explains this principle in his book, *A Brief History of Time*:

> The weak anthropic principle states that in a universe that is large or infinite in space and/or time, the conditions necessary for the development of intelligent life will be met only in certain regions that are limited in space and time. The intelligent beings in these regions should therefore not be surprised if they observe that their locality in the universe satisfies the conditions that are necessary for their existence. It is a bit like a rich person living in a wealthy neighbourhood not seeing any poverty. One example of the use of the weak anthropic principle is to 'explain' why the big bang occurred about ten thousand million years ago — it takes about that long for intelligent beings to evolve [150].

The anthropic principle considers intelligent life a phenomenon that has a cosmological time scale. Therefore, the coincidence of the extrapolated times of humanity's development, despite the inaccuracy of these estimates, may not be an accident. On one hand, if it does have a meaning, the time human intelligence has existed on a cosmological scale is remarkably brief. Even if the 10,000 years of post-Neolithic civilization, some 500 generations are considered on the scale of the Universe, it is very short indeed. On the other hand, as the result of self-organization of living and sentient matter, our civilization now has an impact on the whole planet. The transition to an inherently stable stage of development may signal a period of long evolution, not as tumultuous and hectic as it has been up to the demographic transition.

Chapter 8

Stability Of Growth

History — science of the past,
science of the present.
Luciene Fevre

8.1. Stability of the Demographic System

The dynamics of the global population system describe the hyperbolic growth of the population and the demographic data indicate that on average this growth is globally stable. The large-scale cycles observed in the human population system are the best indications of the overall stability of the system, even though a whole hierarchy of instabilities of a lesser scale do develop and lead to chaos. A number of instabilities develop and various stabilizing factors, migration in the first place, operate locally in the global population system. Such behavior is typical of evolving self-organising systems and mathematical models based on synergetics to describe them have been developed. Aside from applying these models directly, they can also be used as intellectual examples to aid in studies of complexity in order to gain greater insight into complex phenomena.

If the Lyapunov criteria for the linear stability of growth of the 'short' equations are worked out, it is easy to show that the process is unstable. The global population system is least stable at the beginning of the demographic transition when the Lyapunov index reaches its maximum. The contradiction between a linear theory and the details of mankind's growth arises because the 'short' equations that can fully describe the gross features of population growth are insufficient for working out the stability of growth.

These are the internal degrees of freedom which lead to the stability of the system at large and must be accounted for in

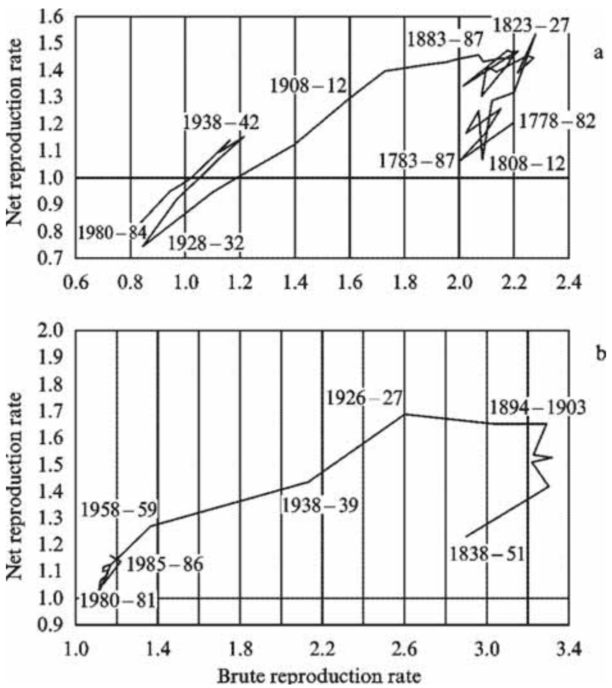


Figure 8.1. Passage through the demographic transition: a — Sweden, b — Russia [55]

a more detailed treatment of how the linear instabilities are stabilized. For example, when the population begins to blow-up at the initial stage of the demographic transition, migration becomes an important factor and damps local instabilities.

According to Vishnevsky, this point is illustrated by the fact that the phase diagrams for the brute and net reproduction coefficients show in detail how the populations of Sweden and Russia passed through the transition. The oscillations observed before and after the transition indicate that the initial and final states are dynamically stable. Even though half of the Swedish population left the country, this oscillatory behavior shows what stability looks like during a major transformation in the population system of an individual country. In a demographically more complex country like Russia, these oscillations are blurred. In the global transition these short-term cycles are difficult to identify because they characterise local attractors.

Table 8.1. World population from 1900–1990
and the losses during the World Wars

Year	1900	1915	1920	1930	1940	1950
N_2	1625	1872	1970	2196	2474	2817
N	1617	1800	1811	2020	2295	2556
DN	–8	–72	–159	–176	–179	–261

Year	1955	1960	1965	1970	1975	1980	1990
N_2	3019	3245	3497	3778	4089	4430	5198
N	2780	3039	3345	3705	4086	4454	5277
DN	–239	–206	–152	–72	–3	+24	+79

N – world populatuon, N_2 – Model of world population, D$N = N - N_2$.

In the case of the global transition, large disturbances are different. The loss of social stability during a war or a large epidemic immediately leads to the collapse of human reproduction. For example, France lost its reproductive capacity during WWI and WWII (Fig. 2.5). In a war, things can only get worse because there are no positive fluctuations in a multidimensional systemic crisis. This has to be taken into account in working out an understanding of the appropriate criteria for systemic stability because it develops as a non-linear phenomenon with many factors reinforcing each other. The general stability of growth is clearly seen in the large-scale behavior of the human population system.

In the past, the system was destabilized at least by two global events — the Plague in the 14th century and the two world wars in the 20th century. Demographic data shows that losses during the world wars were 8%. In spite of this, the global system rapidly returned to the path of stable development, which indicates the gross stability of its growth.

An estimate of the total losses during the wars can be made if the difference between the calculated global population and the population data for the war and post-war periods is calculated. Then the integrated losses are 11 billion people×years. If the effective human lifespan is assumed to be 40 years, the overall losses are 280 ± 10 million people. Demographers estimate the losses at 120–250 million. These estimates are many times greater than the

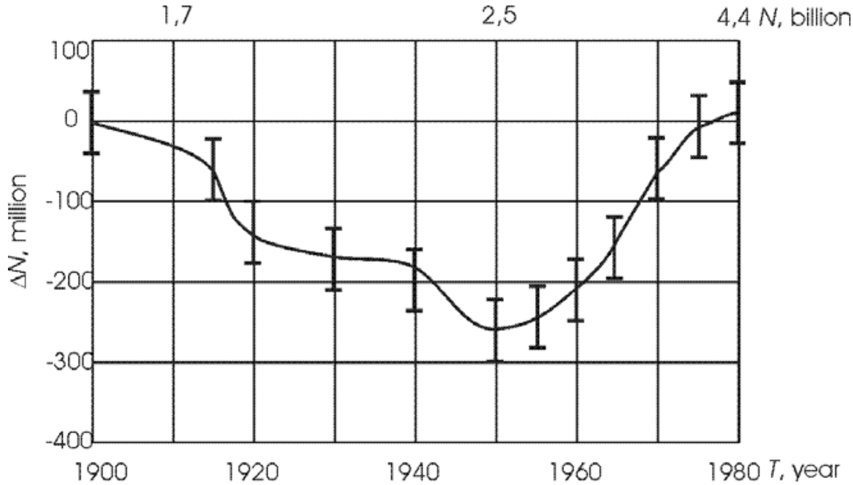


Figure 8.2. Losses of global population from 1900–1980, due to World War I and II

estimated 50 million people who died in action [72]. The indirect population losses — unborn children and early deaths from hunger, displacement or disease — are the main causes of death in modern warfare. For example, after World War I, some 50 million people died from the Spanish Flu, which hit impoverished Europe in 1919. Despite the two world wars, the global population grew from 1.7 billion just before World War I to 4.1 billion in 1975. The global population showed great resilience and the inherent stability of the hyperbolic trajectory of population growth.

In the past, epidemics also led to great losses. The worst epidemic in human memory was the Black Plague that Europe suffered through in the 14th century. In some countries, up to half of the population died and the general losses are estimated at 35 million people, or 10% of the total global population. The epidemic in Europe was triggered by bacteriological warfare. In 1346, the Turks besieged Kaffa, the Genoese Black Sea trading post in the Crimea. The fortified area withstood the siege for two years because it had a good fresh water supply. The Turks threw rats, the vectors of the plague, and entrails of people who had died

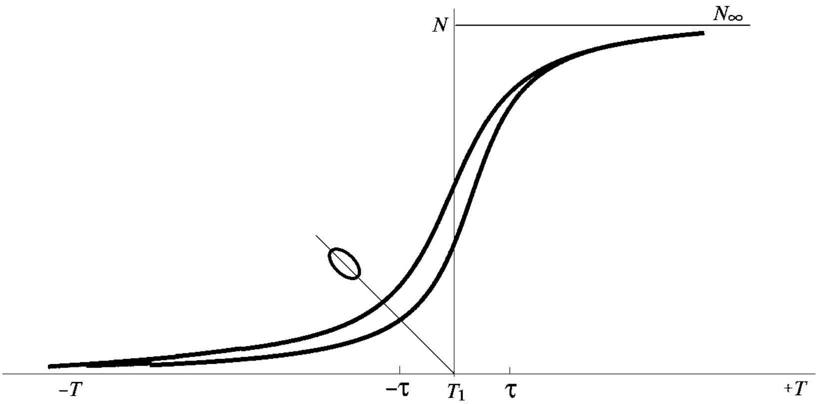


Figure 8.3. Limiting the stable path of growth. A tube of attractors in a multi-dimensional space of dynamic variables, where growth is limited by self-organized criticality, leads to global stability

from it, into the encampment. The infection spread and the fortress fell. (The part of the modern town Feodosia that is located on the old fortress is still called *chumka*, or the place of the plague). The survivors fled on ships and brought the plague to Constantinople and then to Genoa, where it spread to the rest of Europe. The rapid spread of the plague is attributed to a climate change during the 'small ice age' and the poor health of the European population at that time [29, 34]. Despite the losses, the global population recovered and returned to the initial hyperbolic growth curve.

When discussing global stability, it is useful to imagine the path of humanity's development as tube in a multi-dimensional space that confines the motion to a rather limited volume of phase space rather than a line on a plane of time and population. The motion in the tube is only optimal and stable when the point describing the global population is within the tube. Once off the path, things only get worse because the path is a long-term optimal corridor of growth. The internal motions that are confined to the tube, however, stabilize the general path of growth that is otherwise kinematically unstable and contribute to the evolution of the system. The separation of the gross overall pattern of growth from the internal motions, some of which may be locally unstable, provides the basis for using the asymptotic methods to study stability that were developed in synergetics [143].

As the demographic transition is approached, the temporal extent of the large-scale motion of growth gets shorter and finally becomes the same size as the most significant time of internal change — the human lifespan. This is another way of looking at how the system has to switch to another type of growth after the demographic transition. With the onset of the demographic transition, the global population left the course of growth that it had relentlessly pursued for more than a million years and is now transitioning to a new path of development that, in the first approximation, has a zero growth rate.

8.2. History in Terms of Stability

As the transition is approached, the demographic system's stability decreases. This occurred in Europe at the beginning of the Industrial Revolution in the 19^{th} century. At that time, there was rapid population growth and the sudden appearance of a young and active generation that moved from villages to towns. Unsettled and lost in the rapidly growing centres of industry and trade, this generation was the workforce for industrial development and others emigrated to the Americas, Siberia and Australia, or fought in World War I.

Tensions were relentlessly building up on the eve of WWI and the loss of stability can be seen in many lesser events like the wars in the Balkans. This was a remarkable time because Europe was developing rapidly in all fields: industry was growing at rates that have never been reached again; trade and transport expanded worldwide; major and significant breakthroughs and discoveries were made in science, which set the scene for most of what was to come in the 20^{th} century; and art and architecture of the time set the standards for the century. It was the *Belle Epoque*, and Europe never had it so good. The assassination of Archduke Ferdinand in Sarajevo and the loss of stability because of the rapid rate of development triggered the sudden collapse of this world. It took the world 40 years and two world wars to reach a new state of equilibrium, which was far from what the politicians and the military could have ever imagined.

John Maynard Keynes, the economic advisor to the British delegation at the Versailles peace talks, discussed these circumstances in demographic terms in his book, *The Economic Consequences of the Peace*. This seminal book was written after Keynes resigned because he disagreed with the tremendous economic burden the Allies imposed on Germany after WWI. Keynes argued that if driven into a corner, Germany might rebound with horrific consequences:

> Before the war the population of Germany and Austria-Hungary together not only substantially exceeded that of the United States, but also was about equal to that of the whole of North America. In these numbers, situated within a compact territory, lay the military strength of the Central Powers. But these same numbers — for even the war had not appreciably diminished them [1] — if deprived of the means of life, remain a hardly less danger to European order. European Russia increased her population in a degree even greater than Germany — from less than 100 million in 1890 to about 150 million at the outbreak of war; and in the ye ar immediately preceding 1914 the excess of birth over death in Russia as a whole was at the prodigious rate of two millions per annum. This inordinate growth in the population of Russia, which has not been widely noticed in England, has been nevertheless one of the most significant facts of recent years.
>
> The great events of history are often due to the secular changes in the growth of population and other fundamental economic causes, which, escaping by their gradual character the notice of contemporary observers, are attributed to the follies of statesmen or the fanaticism of atheists. Thus the extraordinary occurrences of the past two years in Russia [2], that vast upheaval of Society, which

[1] The net decrease of the German population at the end of 1918 by decline of birth and excess of deaths as compared with the beginning of 1914, is estimated at about 2,700,000.

[2] Including Poland and Finland, but excluding Siberia, Central Asia, and the Caucasus.

> has overturned what seemed most stable — religion, the basis of property, the ownership of land, as well as forms of government and the hierarchy of classes — may owe more to the deep influence of expanding numbers than to Lenin or to Nicholas; and the disruptive powers of excessive national fecundity may have played a greater part in bursting the bonds of convention than either the power of ideas or the errors of autocracy [84].

The collapse of global security at that time had many symptoms of a systemic loss of stability. Even according to the Lyapunov criteria, the rapid population growth could provide a predisposition for a loss of systemic stability. While it may be simplistic to interpret history in such mechanistic terms, there was a loss of global stability and it should be taken into account.

Small perturbations close to the limits of stability are amplified before the system loses stability. In a highly interactive system like the global financial market, the virtual money circulating in the system is considerably larger than the actual investments. Large fluctuations in financial systems indicate that stability has become marginal. The introduction of a small tax on these useless transactions, the Tobin tax, would introduce damping and stabilize the system. This, however, seems unlikely even though the global speculative financial pyramid may be heading for a major crisis.

The world came precariously close to the limit of global stability during the Cold War. Recently mankind did have a chance and, in fact, still does to affect humanity's future in a very direct way — detonating all the nuclear weapons in the world. This could have happened and technically still can because, in the words of one physicist, 'a sweet way' of doing it was invented. The concerted efforts of Bertrand Russell, Albert Einstein and many other concerned scientists, conscientious physicians and eminent statesmen averted this imminent danger to humanity. A huge, completely irrational and utterly obscene number of weapons of mass destruction was accumulated, some 30,000 nuclear warheads on each side. The equivalent of three metric tons of TNT for every person on the planet was ready to be used. That amount could destroy most living beings and cause an immense global climatic catastrophe. The build-up of strategic arms was for mutual deterrence. In other words, the world was kept on the verge of war in a precarious state of unstable equilibrium. Remaining at a virtual state of war that could turn into a real war at any moment was an uncanny way of ensuring peace at an ever growing cost and risk.

During discussions about this MAD (mutual assured destruction) balance of terror, I was always amazed by the technocrats, who toyed with these concepts and were somehow unaware that the loss of stability meant the loss of any control over what would happen making the plans and grand designs of the General Staff meaningless. Some generals' planning discussions for World War III were like soap operas and did not even remotely resemble what could really happen (See *The Third World War* by General Haskett). During those discussions, thinking in terms of non-linear systems dynamics certainly helped to develop an understanding of the issues at stake — the fate of the world as we know it.

In a dramatic and straightforward way, the Chernobyl accident was a significant event that made the Soviet leadership and the world face some of the realities of the nuclear age. The accident was caused by an explosion of a reactor at a civilian nuclear power plant that experts said was so safe that it could have operated on Red Square in the centre of Moscow. Chernobyl was less a technical accident than a systemic catastrophe that had deep social and cultural roots [6]. Systemic thinking is important when assessing the delicate balance of terror of the nuclear arms race or the message of Chernobyl. Without taking into account sociological, human and managerial factors, it is impossible to understand what happened and learn the appropriate lessons from the accident. These exercises in complexity are one of the prerequisites for studies in demography. As the hardware of our civilization rapidly changes course, its software — our social consciousness and culture — has no time to react, properly develop or keep up with the challenge of global change generated by the restless spirit of human endeavour. This clash between the global civilization and the diversity of cultures is emerging as a major issue that is dividing the world.

Concerned leaders of the Muslim world recognized this and Iranian President Khatami presented the issue to the United Nations. UN Secretary General Kofi Annan commissioned an international group of scholars to explore this issue. After a year of discussions, the working group approved the final version of the book, *Crossing the Divide: Dialogue among Civilizations,* in Qatar on 8 September 2001, three days before 9/11. The book [104] was presented to the Secretary General in New York two months later, and the members of the group were invited to address the General Assembly. I spoke about the 20-year-long dialogue between American and Soviet scientists on the menace of a global nuclear war. Without this dialogue, which laid the foundation for the agreements that were largely responsible for defusing the Cold War, there were chances that not much would be left on the planet if a nuclear war broke out.

The recent wars in Afghanistan, Iraq and Chechnya demonstrate that the total destruction of civilised life is possible without nuclear weapons. Therefore, a dialogue is the only real option for resolving a major conflict. Achieving this new way of dealing with the differences in a rapidly changing world is difficult because events in all dimensions (economic disparity, stresses due to industrialisation and urban development, large migrations because of economic, religious and ethnic differences, etc.) are happening too quickly. The speed at which a new understanding can be developed and entrenched attitudes and values reassessed is the main obstacle to resolving confrontations in the modern world.

8.3. Global Security in the Future

Major instabilities cannot be predicted, but critical trends should be recognized. In the developing world, the changes are happening twice as fast as they did in the developed world when it was at a similar stage, however, the size of population involved now is 15 times greater. China's double digit economic growth and India's 6–7% indicate that these countries, passing through the demographic transition, may become a source of regional, or even global, insecurity in the critical area of South-East Asia and the Pacific. This region is the third and last 'Mediterranean' of the world. The Atlantic was the second and the Mediterranean Sea

Table 8.2. Population dynamics for the world, Asia and Europe

	1950			2000			2050		
	World	**Asia**	**Europe**	**World**	**Asia**	**Europe**	**World**	**Asia**	**Europe**
Population (mln)	2500	1400	580	670	3740	730	9800	5700	700
Growth (% per year)	1.78	1.90	0.96	1.49	1.55	0.08	0.54	0.44	–0.2
Child death per 1000	156	180	72	57	57	12	17	17	6
Children per 1 woman	5	6	2.5	3	2.9	2.16	2.1	2.1	2.05
Density per square km	19	44	24	45	118	32	72	181	29

was the first. In this new world, Europe will be a small community but may retain, as its main asset, its cultural and scientific potential and face growing pressures on its southern and eastern borders [83].

The demographic indicators are a message for contemplation and action. The appropriate demographic policies should be defined and pursued in national, social and economic plans for development. Most governments have such programs and in response to these issues, China, India and Indonesia pursued different policies. Vishnevsky discusses the demographic situation in Asia:

> On one hand, we see the rapid quantitative growth of Asia in the world balance of people. In this sense it may be said that Europe has lost forever to Asia in terms of numbers. On the other hand, Asia is inherently unstable, as it is suffering under great internal problems that threaten the very physical existence of its population. In this sense, even the success of demographic policies can be seen in terms of a loss. The demographic explosion of a huge magnitude — the population grew 2.7 times from 1950 to 2000 or 4.1 times from 1950 to 2015 — has brought innumerable difficulties. Here we have a growing density of population that was always high in Asia and has become even greater. This leads to a cut in the economic investment for growth, to a degradation of the environment that always accompanies rapid population growth and the continuing existence of the old economic systems. These economies do not have time to evolve in the rapidly changing circumstances of the demographic transition.

> The present demographic explosion in Asia is a result of the incomplete demographic transition. In other words, by following the European pattern of development, the decrease of the mortality is a positive factor, but the European way of decreasing population growth is a negative one. This leads to a collapse of the equilibrium of the demographic system, as a new state of equilibrium cannot be reached. The unacceptability of a decrease in fertility comes from traditional culture that defends its values. In a certain sense, this can be seen as a positive factor, for culture protects and stabilizes the society. But life and the rapid changes of the modern world lead to a contradiction between the 'mystique' of culture, and with the Cartesian clarity of modern science these processes have to be seen as they are. If a system that is losing its equilibrium because of rapid growth and positive feedback can finally be stabilized by forces with a negative feedback, this has yet to happen. The only alternative in terms of demography is a growth in mortality to its pretransitional level. If we renounce such retroaction, then the only chance is to decrease the birth rate. In many ways, we are now too late.
>
> A balanced view of the realities of demography forces us to be careful in assessing the economic success of Asian countries (with the exception, in terms of demography and economics, of Japan). The growth of population produces great resources for extensive development by offering very cheap labour, but this does not facilitate independent technical progress. The conservative demographic traditions are intimately connected with social traditionalism, which itself does not allow for a rapid modernisation of Asian countries. In this case, development often is limited to enclaves in an ocean of agrarian societies. Asia in this sense is similar in a way to Russia at the end of the 19th century, and may repeat the dramatic path of Russia in the 20th century. But this time it will affect not 200 or 300 million but 5 or 6 billion.

Regional security will be threatened by demographic gradients across international borders. The population is declining in the vast, sparsely populated spaces of Siberia, while the population in neighbouring China's northern provinces is rapidly growing creating a precarious stability. Similarly, Indonesia's population is exploding and has passed 200 million people, while Australia has a population of less than 20 million.

The immigration of Hispanics into California is another example of what happens in the less violent cases of diffusion over pronounced demographic and economic gradients. Demographic factors are significant in recent developments in Islamic countries, which are practically all experiencing the population blow-up at the initial stages of the demographic transition with the numerous complications that accompany it. The forces of the demographic imperative, rather than a clash of civilizations, drive conflicts regardless of whether they are in Algeria or Kosovo, Chechnya or Afghanistan. Central Asian countries are also in a highly charged state and demographic pressures threaten the strategic stability of the region.

Urbanisation, when large masses of people migrate from villages to towns, is a major source of internal instability for many developing countries. Huge megalopolises are literally blowing up, relentlessly drawing in people from all over the country and attracting immigrants from abroad. Given China's present rate of growth and the differences in regional economic development, one of the government's highest priorities is the threat these factors pose. In this case, the conservative policies that prevent disintegration of the realm and the social fabric of the country should be properly understood. Even though the liberalisation of economic development has led to remarkable growth, regional differences have also increased and could develop into a threat to stability.

Terrorism is currently considered the main threat to stability. Terrorism appeared in many countries in the 19th century with the advent of the demographic revolution. The growth of terrorism was both symptom, a precursor and, finally, a trigger of World War I. This scenario could repeat itself and have dire consequences for global security in the modern supercharged and unstable world. Among the complex reasons for terrorism, economic inequity and the strains caused by population growth are the leading causes. In fact the growth of terrorism with the collapse of any law and order in military conflicts, established in the past by tradition or treaties, can definitely be attributed to the tensions and inequities in the non-equilibrium state of the world as it passes through the demographic revolution. These considerations should be taken into account in any analysis of the causes of terrorism as a global phenomenon.

During the demographic revolution, a lack of global security is the greatest threat to systemic stability. Now that nuclear weapons have proliferated to regions with the highest growth rates the potential danger is the greatest. That is why an account of these threats and efforts to avert a general instability should be high on the global agenda. For no one can afford a world war on a scale many times larger than the 20th century global conflicts. Global security is commonly discussed in terms of military, economic and ecological issues, but in the long run the demographic factor is the most important one.

Chapter 9

Resources, Energy and Population

> Population and the quality of life have to be seen in the context of development, that is, improving the conditions for life at the individual and collective level. It is important to go beyond the traditional oppositions between North and South, development and underdevelopment, between communities and individuals, among sectors within countries and even communities.
>
> ***Ricardo Melendez Ortiz, Columbia***

9.1. The Open Model and the Population Imperative

The model is a phenomenological description of the growth of the global population, an interacting and open system. The global population system is both isolated and open, which means that it can draw on the resources from the environment. The theory does not contain any constraints or limits to external resources and in economic theory this type of resource is called 'an open-access resource'. Nevertheless, some think that external conditions limit growth and therefore the profound transformation the population is currently going through, the demographic transition, is a result of a lack of resources.

According to the model, growth is determined by the internal process of development, which is driven by the collective global interaction and not limited by resources. The quadratic interaction is an internal factor, is solely dependent on the total population, and is not dependent on external parameters. In fact, throughout history, mankind has always had enough resources regardless of whether man needed space, food or energy. If at any point local resources became limited, then people moved to other places, eventually spreading throughout the world. Man traditionally settled near large rivers. Indeed, most civilizations grew along waterways, which serve as trade routes and cultural centres, and are still a permanent feature of human life.

While famines have certainly hit human populations throughout history and a lack of food can lead to great local losses of life, on a larger scale, humanity has always persisted and its growth has shown remarkable resilience up to the moment of the demographic transition. In the framework of the model, the force driving growth is the global co-operative interaction, and the only resource that currently limits growth and development is the time for a generalised information exchange. Global population data and modeling indicate that there are currently no direct symptoms of external factors affecting population growth and that no marked change in the distribution of the global population has occurred yet, although with the decline in TFR in developed countries this may lead to large migration from the developing countries which sustain a high birth rate.

9.2. Energy and Population Growth

Energy is the most significant factor in growth because it is the main resource for development and it determines food production, transport, industry, housing and communications. Like the population, energy production is additive and readily quantifiable. There are reliable global energy statistics from as early as the beginning of the 19^{th} century at the start of the Industrial Revolution. All forms of energy can be compared and measured by the same universal units. This major resource, regardless of whether it comes from wood, coal, oil, gas, hydroelectric, nuclear, wind or solar sources has been summed up by John Holdren for the world and then compared to global population growth [115].

At the beginning of the 19^{th} century, the global population was about 1 billion and the average power per person was less than half a kilowatt, or, half a horsepower. If this data is extrapolated to 1 CE, the power available would be ten times less and roughly correspond to the power a human is able to produce by himself. Although these estimates are very approximate, they show the

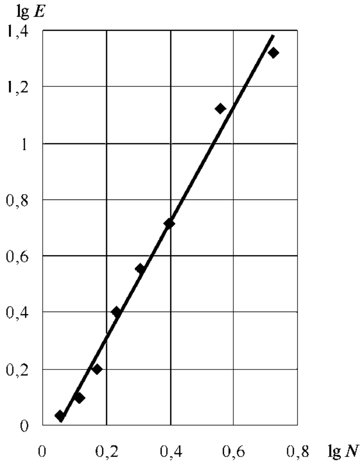


Figure 9.1. Scaling global energy production 1850–2000: $E \approx N^2$

Table 9.1. World energy consumption

Year	Population Billions	Energy TWatts•Year
1850	1.13	0.68
1870	1.3	0.79
1890	1.49	1.0
1910	1.70	1.60
1930	2.02	2.28
1950	2.51	3.26
1970	3.62	8.36
1992	5.32	13.3
2000	6.10	14.5

scale of energy's contribution to humanity's growth and development and when input from other sources became significant.

According to Holdren's data, energy production has grown twice as fast as the population since 1850. In relative terms, this means that for every 2% increase in energy production, 1% is from population growth and 1% is from an increase in energy consumption. In other words, the production of energy is proportional to the square of the population and follows the same law as the population growth rate. The global interaction driving growth is powered by the energy supply and the population system is much like a giant machine driven at an accelerating rate by an expanding energy supply.

While this is a quite mechanical description of growth and development, it provides some understanding of the nature of what is happening. The global population grew by 4.3 times and the energy production increased 17 times from 1850 to 1990. The power per capita is proportional to the global population Q(watts) = $470N$ (billions). In 2000, mankind consumed 14.5 Twatt ´year or the equivalent of 14 billion metric tons of coal per year. The average annual consumption of energy per capita was 2.3 metric tons of coal in 2000, which is on the same order of magnitude as the per capita explosive power of the nuclear weapons accumulated during the arms race. In terms of space travel, the per capita energy is on the same order of magnitude as the energy required launching a human being into space.

Until the demographic revolution, the total energy output grew faster than the population, although the relative growth rate of energy is less than it was a decade ago. In developed countries, energy growth is less than it was before the demographic transition and energy growth has even stopped in a number of countries. In the former Soviet Union, energy production has decreased because of a profound economic crisis, the demilitarisation of the Russian economy and the pressure on industry from the greatly increased cost of energy — a direct and sensible result of market forces. In the US, energy consumption has also either stabilized or stopped growing as it once did. In the US, in fact, the energy growth rate is equal to the population growth rate — 0.5%. Many large energy consumers have moved production out of the US and the American economy has become service oriented and demands less energy.

In *Factor Four,* a report to the Club of Rome, Lovins, Lovins, and Weitszaker discuss the promise and impact of energy saving technologies and suggest that energy consumption could be cut four times in the developed countries, primarily through the use of advanced technology and energy saving devices and measures [126]. Many developing countries are emulating western energy policies. They are climbing, or rather leapfrogging, up the energy ladder by moving from wood to coal, from coal to oil, from oil to gas and finally, from gas to nuclear energy [131].

The rapidly developing world, therefore, will not only build up its energy resources faster, but follow a qualitatively different path than developed countries because energy production methods are now generally available For example, India and China have large nuclear energy programs, and South Korea already produces 40% of its energy from nuclear sources. If the energy production in developed countries will stabilize with the population, the developing countries are rapidly building up their energy production. The annual growth in India is 4.5%, 6.5% in South-East Asia and in China is 6%, although China still uses coal and is presently mining a billion tons a year, more than any other country.

It can be expected that the world will have all the energy it needs to follow the demographic imperative of population growth. (See the recent exhaustive study by Smil [134].) Energy is still the main commodity and the energy sector is roughly 15% of the world economy and it is now generally recognized that all available energy resources, including nuclear energy, can meet future energy demands. Only a rough estimate of how the energy situation will change during and after the demographic transition can be made. As the global population will double and energy production is growing much faster than the population, then energy production per capita will be 4–6 times greater. In this case, the power of the global energy system could reach 50–60 Twatts by the end of the 21st century. These are the upper limits and they generally correspond to the World Energy Council's estimates [131]. These calculations trace the long-term pattern of energy production of global averages.

A number of observers have indicated that fresh water may limit global development. While energy at present is mainly a non-renewable resource, water is a renewable resource when it circulates in the global hydrological cycle. Presently, less than 1% of human effort is engaged in supplying water, an order of magnitude less than the cost of energy. In other words, the scarcity of water is a matter of its distribution and use, not its inherent physical scarcity.

9.3. The Environment

The focus of discussions about the long-term energy future of humanity is on the impact of energy and industry on the global environment. Some people place greater importance on the environment than on the population, to the extent that an environmental imperative is pronounced [113, 121]. Throughout human history, man has been dominant at the expense of degradation of the environment. In most of Europe, the environment is no longer natural. China, which has the highest population density along its great rivers, has an even larger the impact on the environment and the Chinese population has lived in an artificial, but stable and sustainable environment throughout history. These conditions of life are far from those practised in Europe, but they have been sustained in one of the oldest civilizations. A comparison of India and Argentina is a good example of the influence of food resources. Argentina is only 30% smaller than India, however India's population, over 1 billion people, is 30 times larger than Argentina's population. India, a subcontinent, has an ancient culture, while modern development began in Argentina about 200 years ago. According to experts, Argentina has enough agricultural resources to theoretically feed the world. Humanity's self-similar pattern of the development shows that there are enough global resources and that these resources do not limit population growth and be the Malthusian reason for the demographic transition.

The impact of energy production on the climate has led to a heated debate that is difficult to summarise impartially. When considering the impact of man on the climate regarding greenhouse gases, note that only part of the greenhouse gasses are from energy production and burning fuel. A substantial portion of greenhouse gasses come from agriculture. For over a million years, the growth and development of the global population system has shown great resilience. Humanity has a huge amount of resources at its disposal, though the resources are not presently being used in the best or optimal way.

A frequent claim is that global warming could lead to a rise in sea levels resulting in the flooding of countries like Bangladesh. Since the 16th century, the Dutch have used windmills and primitive technology to reclaim half of their land, which is currently about 6 metres below sea level. While the Netherlands is and was a densely populated country, Bangladesh has far more human resources per mile of coast than the Dutch did 400 years ago. Modern technology for building dams or moving water away from threatened territory is also available to Bangladesh. These calculations are only hypothetical options because they ignore social, economic and political factors. Without these calculations, however, it is useless to appeal to the world on energy policies and make frightening projections.

Table 9.2. The carrying capacity of the Earth

Source	Earth's carrying capacity (billions)	Date
Ravenstein	6	1891
Penk	7.7–9.5	1925
Pearson and Harper	0.9–2.8	1945
Baade	30	1960
Clarke	47–157	1967
Revelle	41	1967
Muckenhausen	35–40	1973
Buringh *et al.*	2.7–6.7	1975
Westling, Mann	About 2	1981
Simon, Kahn	No meaningful limit	1982
FAO/UNFPA/IIASA	2–30	1975
Higgins *et al.*	3.6–33	2000
Gilland	7.5	1983
Resource for the future	6.1	1984
Marchetti	1000	1978
World hunger program (Cohen)	2.8–5.5	1992
Erlich *et al.*	Less than 5.5	1993

A number of authors have raised the issue of the carrying capacity of the planet, and a detailed discussion of the subject can be found in a collection of papers published by the IIASA, *The Future Population of the Earth: What Can We Assume Today?* [74]. In his chapter, *How Many People Can the Earth Feed?,* Heilig cites estimates of the Earth's carrying capacity ranging from 1 billion to 1 trillion. The last estimate by Marketti's of 1 trillion is quite extravagant and really out of context. Heilig successfully argues that most of these calculations are based on inconsistent and incorrect methods and approaches. A global population limit lacks real meaning, if it is considered without the evolution of social and economic conditions and the development of science and technology. Heilig concludes that the Earth can support 15–25 billion people in reasonable conditions. After a detailed discussion of the limitations of agriculture and the available resources, Heilig sums up:

> If we take into account the creative potential of man, there is no foreseeable limitation to the basic natural resources of food production, which are space, water, climate conditions, solar energy, and man-made inputs. All these resources are either unlimited or

> can be expanded, better utilised, or redesigned to a very large extent. This might be the reason why several experts have denied any upper limit to population growth. The notion of 'physical limits to growth' is a faulty concept. It makes it easy for agricultural technocrats to deny any basic problems in boosting the world food supply. Better arguments must be found to convince people that global food production may be limited [74].

In *Preparing for the Twenty First Century,* historian Paul Kennedy adds to the debate about resources, the environment and the growing demographic disparities of the world:

> From the viewpoint of environmentalists, therefore, the Earth is under a two-fold attack from human beings — the excessive demands and wasteful habits of affluent populations of developed countries, and the billions of the new mouths born in the developing world who (very naturally) aspire to increase their own consumption levels. This in turn has led to a number of environmentalists voices — the Worldwatch Institute [116], Greenpeace, the United Nations Population Fund — to portray the entire issue as a race against time. In their view, if we do nothing to stabilize the world's total population, curb the profligate use of energy, foodstuffs, and other raw materials, and control damage to the environment, as soon as possible, then before very long we will have so overpopulated and ransacked the Earth that will pay a heavy price for our collective neglect.
>
> This viewpoint, which challenges the assumption that growth is desirable, and economic output is the most useful measure of a country's material success, has provoked counterattacks from many economists. In the optimist's opinion, natural resources are not an absolute amount that is steadily being depleted; rather, many resources are created through human inventiveness and labour, and technology has an infinite capacity for producing new resources. The scarcity of a commodity, such as petroleum, leads to the search for (and discovery of) fresh stocks and the creation of alternative forms of energy, alarm at the levels of world food production leads to significant increases in agricultural productivity from breakthroughs in biotechnology, and so on. Just as Malthus was incorrect in his predictions, so will today's doomsayers be proved wrong.

> Only time will tell which of these positions is more accurate, but the world's population was less than a billion when Malthus first wrote his Essay; now it is heading, at least, towards 7 or 8 billion, perhaps to well over 10 billion. If the optimists are right, the world will simply contain many more prosperous people, even if that prosperity is unevenly distributed. If they are wrong, the human race as a whole could suffer more from a careless pursuit of economic growth than it may lose by modifying its present habits [95].

In *How Many People Can the Earth Support?* Joel Cohen presents a detailed review of the carrying capacity of the Earth. His central argument is that the limits are not physical, technological or environmental, but economic and social. In his conclusion to a discussion about the long-term trends in a world with a stabilized population, Cohen lists eight unresolved issues:

> 1. How will the bill for family planning and other population activities be distributed between the developing countries (who now pay perhaps 80 percent) and the rich countries?
>
> 2. Who will spend the money, and how? How will the available monies be allocated between governments and non-governmental organisations? How much will go for family planning and how much for allied programs like reproductive health?
>
> 3. How will environmental goals be balanced against economic goals? For example, if reducing poverty requires increased industrial and agricultural production in developing countries, can the increase in production be achieved at acceptable environmental costs?
>
> 4. How will environmental goals are balanced against cultural continuity? In some cultural settings, the goal of empowering women directly contradicts the goal of maintaining 'full respect for the various religious and ethical values and cultural backgrounds'. Both goals were often repeated in the final document of the 1994 International Conference on Population and Development. Women achieved the vote in the United States only in 1920 and only after considerable struggle. Asking for equality for women now asks some cultures to make a far greater change in far less time. I fully support such demands, but they should be made with a clear and sympathetic understanding that they require profound cultural change.
>
> 5. How will the often-asserted right of couples and individuals to

control their fertility be reconciled with national demographic goals if the way couples and individuals exercise that right, happens not to bring about the demographic goals?

6. How will national sovereignty be reconciled with world or regional environmental and demographic goals? This question arises in the control of migrations, reproduction and all economic activities that involve the global commons or atmosphere, oceans and international water bodies, and the management of the plant and animal populations that inhabit them.

7. How will the desire and moral obligation to alleviate poverty and suffering as rapidly as possible is reconciled with the use of local scarcities as an efficient market signal?

8. In efforts to protect the physical, chemical and biological environment provided by this finite sphere, how will rapid population growth and economic development in poor countries be balanced against high consumption per person in the rich counties? [122].

It should also be noted that 2% to 4% of modern countries' populations could feed the country. According to a statement by experts from the Food and Agriculture Organisation, there is enough space and resources in the world to produce food for 20 to 25 billion people.

These points indicate some of the main contradictions that arise in the modern world. It may be concluded that in principle, there are no physical or technical limits to providing the expectant global population with food, although distribution problems caused by local social and economic conditions can and do lead to local undernourishment and famines. Amartija Sen discusses the limits imposed by food production and comes to the conclusion that it does not basically limit in the long run the growth of population, for locally lack of food and hunger are the result of a breakdown of the distribution system [111]. Le Bras refutes the argument that urbanisation is responsible for the demographic transition [68].

From a consistent systemic point of view, population growth is determined by global population dynamics, which are driven by the population imperative's priorities. This does not mean that nothing can or should be done. Nevertheless, humanity's behavior at large is an expression of systemic development that statistically adds up to global growth. By using a statistical approach, these issues are incorporated in an integrated treatment of global population growth. Initially it may seem like nothing has to be done because the global population system, including the development of people's attitudes towards theses issues, will progress naturally. The limits of human reasoning largely restrict the amount of control, influence responsibility mankind has over its future. The nature of the global interaction, which according to this interpretation is an expression of human consciousness, includes man's capacity to develop new technologies and govern himself.

This does include the evolution of consciousness itself, or whatever is the agent responsible for development. As an element of the system at a higher level of self-organisation it will have an effect on our future and in that way secure our development. While this may seem like a circular argument, it should be recalled that the collective global interaction has already taken humanity rather far. The demographic imperative has been successful in explaining humanity's past and, although humanity is currently passing through the demographic transition, this concept can also be used to describe the future. In other words, the global population system learns and develops its own thinking — the ultimate meaning of the global interaction. The assumption of the validity of modeling in the model accounts for this interaction [133].

This issue is reminiscent of the old conundrum: 'If God is omnipotent and omniscient, can He by His wisdom create a stone that He cannot lift?' The solution to this paradox is that God, through His omniscience, knows how to resolve the paradox but humans, with their feeble minds do not. Mankind can make things worse, however, by creating major disruptions in society like wars. Modern weapons of mass destruction still threaten the existence of humanity, although this danger has largely been averted. When the human population system has evolved independently it has been very successful in developing. Therefore, before mankind interferes in this development, it needs to reach an understanding of how the population system has managed to get this far against all odds.

In contrast to some calls, coming mainly from environmentalists, for drastic measures to control population growth, there will be enough resources in a world with a stabilized and stable population of 10–12 billion to support the global population system.

Russell Hopfenberg and David Pimental have come back to arguments of how the food supply limits population [132]. They argue that like all other species food and biological/ecological factors set limits for and determine population growth, but ignore that through agriculture the human population has become much larger than all other comparable creatures. Despite the large number of references used, none of these authors uses quantitative data or models to justify their findings. The authors even suggest that the proposed relationship between food and population are to be the basis for addressing this global problem. By the authors' own admission their wishful thinking is resisted by a cultural bias to this attitude by science. Lutz said that David Pimental's suggestion that the global population could be reduced to 1-2 billion if fertility was limited to 1.5 children per family was simply wrong. If families were limited to 1.5 children after 1995, the population would still rise to 6.6 billion in 2025 and then slowly decrease to 3.5 billion by the end of the 21st century and, if the TFR is less than 2.1 this population is heading for extinction. These calculations show how irresponsible and misleading statements about this serious subject can be. To continue to argue these points is an insult to human nature, and shows a lack of understanding of the issues involved. The same is true of the idea to limit the population to a 'golden billion', leaving the rest doomed to poverty.

Population dynamics, especially on a global scale, has its own drive and logic and only when an in-depth and fundamental understanding of these complex interdisciplinary global problems is reached can these universal issues be faced and responsibly resolved by sensible demographic and economic policy. Demographic data has repeatedly demonstrated that these problems are complex and that any direct intervention is essentially unproductive. For example, population growth in a Catholic and a non-Catholic country at the same stage of the demographic transition is the same despite the Catholic Church's attitude towards birth control and procreation. For example, the TFR in

Italy is 1.12 and in Spain — 1.07. Both TFR's are well below the 2.1 TFR required for a stable population regardless of its size.

On the other hand, the long-term impact of the harsh population control methods practised in India, Indonesia and China has permitted these countries to escape the poverty trap. In that case, the population explosion at the beginning of the demographic transition cannot be supported by economic development because all the output of industry is initially taken up by population growth. As a result of this mismatch of development and growth, these countries get stuck in a low productivity poverty trap. At present these newly developed countries, once there industrial development has take on, can lessen the effort in limiting the birth rate to sustain the population.

9.4. Do Resources Limit Growth?

In the future, humanity may reach a stage of development when resources could limit growth, as is assumed in conventional Malthusian wisdom. The global population distribution is far from uniform. If there were a general lack of resources, there would be a much more uniform population distribution. Although there have been massive movements of people in the past, migration currently involves less than 0.1% of the global population a year, which is a flux an order of magnitude smaller than the annual population increase (Table 3.1). This may indicate that globally there are enough resources and that any local deficiencies are the result of disruptions in society like war and famine or poor governance.

The population explosion in developing countries presently is a greater threat to security than a perceived lack of resources. The disparities in population distribution and resources are the important factors because they are the causes of most current economic, political and military problems. The main reason for migration is economic inequity, which, amplified by demographic and ethnic factors and expressed by political pressures, has led to revolutions and war on many occasions.

Global modeling is another attempt to take into account the main factors responsible for the growth and development of the global system. Jay Forrester pioneered the approach in his book *World Dynamics* [106]. The first report the Club of Rome commissioned in 1972, *Limits to Growth*, [107] is based on these ideas and written by a group of scientists from the Massachusetts Institute of Technology. In the *Limits to Growth* models, five variables are used to describe the state of the world: population, capital investment, natural resources, the portion of capital devoted to agriculture and the portion of capital devoted to pollution, which indicates the level of aggregation. The dynamic network requires a matrix of coefficients to couple all variables. Unfortunately, most of the variables were based on educated guesses and their interdependence.

Complex computer-based models that have comprehensive inputs from extensive databases were developed for these studies. These models supposedly take into account most of the factors that influence development. These models follow a reductionist methodology and did provide a new insight into the growth of the global system and drew attention to the possibility of global modeling, which opened up a new field of studies.

Two significant points, however, were not taken into account. There is no evidence that the system was complete or that it accounted for enough factors to provide a model valid for a sufficiently long period. Next, there is no explicit connection between development and population growth. These global models were never tested by working out past growth and development. While of less practical value, this could give some insight into the validity of the methods.

The results of these initial models have been extensively criticised. See Smil [134]. In his criticism of the approach, American economist Nordhaus comments:

> The model contains 43 variables connected by 22 non-linear (and several linear) relationships. Not a single relationship or variable is drawn from actual data or empirical studies.

The main connection between population and food is based on the Malthusian principle:

> It appears that the world population has normally existed in that sensitive region where food regulates birth and death rates so that the population maintains its precarious existence at the maximum number of people that the available food can sustain.

At this point Cohen makes an appropriate remark:

> Decide for yourself how well this statement describes any region of the world of which you have first-hand knowledge [122].

In their recent book, *Beyond the Limits* [117], Medows et al. focus on exponential growth and disregards the systemic nature of global development, although in their latest comments mention is made of cultural factors affecting growth and development. The most important and widely recognized outcome of this work was the general recognition of the fundamental significance of global problems. But a valid method to deal with the complexity in global modeling requires a new approach and a basic change in one's attitude and mindset.

In 1974, Mesarovic and Pestel presented the next report to the Club of Rome, *Mankind at the Turning Point* [108]. In it, they extended the initial studies and emphasised the importance of global interdependence. This has been discussed in the past by a number of authors in the wake of the first Report to the Club of Rome. Ervin Laslo presented a report, *Goals for Mankind,* to the Club of Rome in 1974 [139].

The Next 200 Years: A Scenario for America and the World by Herman Kahn, William Brown and Leon Martel and with the assistance of the Hudson Institute's staff is an assessment of the heated controversy about global development that occurred 25 years ago [109]. This book amplifies the message of Kahn's first book, *On Thermonuclear War*. The primary focus of the study is long-term trends, rather than short and medium-term issues. The demographic transition is emphasised as a general transformation taking place in the world. The general attitude of the authors is rather positive and, when discussing the Malthusian limits to growth, they suggest an abundance of resources and refute the idea of 'limits to growth':

> The post-industrial world we foresee will be one of increased abundance, and thus hopefully of reduced competition; it will be one of

> greater travel and contact, and thus possibly one of diminished differences among its peoples. But it will also be one of enormous power to direct and manipulate both man and nature; and thus its great issues will still be the very questions that confront us now, though enlarged in range and magnitude: Who will direct and manipulate, and to what ends?

These studies made an important conceptual step because they brought global problems to the forefront of a global debate. Since the first Reports to the Club of Rome, much has been done to develop what has become known as 'the global *problematique*'. The club's motto became 'Think Globally, Act Locally' [114]. Nevertheless, the attempt to reduce the population system's growth and development to a detailed summary of all contributing factors contradicts the notion of thinking globally. Thinking globally has to be consistently systemic. These issues are even more significant today because globalization has become a universal trend.

The current primary limit is time because the acceleration of population growth cannot be kept up. If the global population system continued to pursue a self-similar pattern of growth, as it did in the past, the population in 2000 would be 8 billion and not 6 billion. Two billion is an order of magnitude greater than the losses during both world wars and shows the magnitude of the factors involved. But nobody has ever lamented the 2 billion people lost when the global population system abandoned the pattern of growth that began more than a million years ago.

In the first approximation, the resource-imposed limits are not included in the global population growth theory. It may seem like a circular argument to exclude the resource-imposed limits in the 'short' equations because what will be proved is assumed beforehand. This is not the case, as the development of mankind is consistently described from its origin by the same model, and the present cut-off is definitely not due to a limit in space, food or other resources. As this analysis demonstrates, the limit is in the capacity to grow and is determined by the limitations of the global generalised informational interaction and, ultimately, by the global software, by culture, rather than the hardware, material resources of our civilization.

9.5. Distribution of Population in Space

Before the Neolithic, tribes migrated in search of food and few details are known about the distribution of the population. It can be assumed that hunters and gatherers, and later nomads, would have constantly moved. Early man was only able to settle down in one place because of the invention of agriculture and after the Neolithic revolution man began to concentrate in villages and towns. Maps and studies show the chaotic distribution of population [46, 72], which can then be described by fractals, developed by Benois Mandelbrot [142]. For example, Le Bras used multifractals to describe the distribution of the French population [69]. These fractal distributions indicate that such growing and evolving dynamic system are far from equilibrium.

When ranked by size, the distributions of population centres in individual countries are generally hyperbolic, but the ranking breaks down when extended to large towns. In this case, it is usually remarked that large towns are special and that the ranking cannot be extended that far. For example, in a distribution for Japan, Tokyo will appear as a disproportionately large town because in 1985 Tokyo was the largest in the world. The global population system, however, allows for a distribution for all towns, including and beginning with the largest, to be suggested (Fig. 9.2).

The distribution has a logarithmic cut-off for the largest towns (Insert A shown on a linear chart) and provides a satisfactory distribution without introducing additional constants. This distribution indicates the limits of scaling, and provides an estimate at $U=1$ and $\sim 10^8$ for the number of homeless people, which Vorotzov estimates is about 2% of the population. The population of the largest town U_0 with rank zero is determined by solving a transcendental equation (A39) for the global population and can be applied to the past. At the height of the Roman Empire, the global population was 100–200 million and the calculated population of ancient Rome is U_0 = 1 million. This is close to the estimates of historians for the Eternal City where the Coliseum could seat 50,000 people. These numbers indicate the remarkable level of self-organisation in the Ancient World, where in Rome a stable life

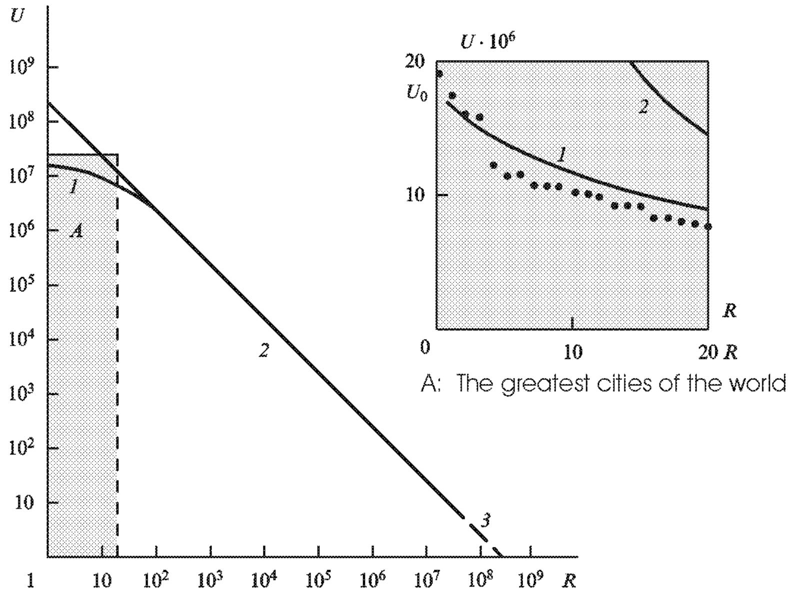


Figure 9.2. Ranking the global distribution of towns by size (1985). R — rank

Insert A: R=0 — Tokyo, 1 — Mexico, 2 — San Paulo, 3 — New York, 4 — Shanghai, 5 — Calcutta, 6 — Buenos Aires, 7 — Rio de Janeiro, 8 — London, 9 — Seoul, 10 — Bombay, 11 — Los Angeles, 12 — Osaka,13 — Beijing, 14 — Moscow, 15 — Paris, 16 — Jakarta, 17 — Tianin, 18 — Cairo, 19 — Teheran, 20 — Delhi

could be sustained by an economy and technology far from present standards. In modern Rome 2 million people live although the city's population dropped to about 30,000 after the fall of the Roman Empire.

According to the model, Beijing's population at the end of the 18th century was 3 million, which corresponds to a global population of 700 million when the actual global population was approximately 850 million. (Table 4.1). In the future, when the global population stabilizes at ~10 billion, the population of the largest town could reach ~40 million, which is not far from reasonable estimates. These calculations are in agreement with historical data and provide yet another indication of the interactive nature of the global population system.

9.6. Distribution of Wealth in the Global System

Usually, the distribution of wealth, like the ranking of towns, is analysed for each country and described by a Pareto distribution, a generalised hyperbolic power law. Fractal power laws are typical of systems far from equilibrium, established by the recursive pattern of the processes inside an evolving and growing dynamic system, and show the degree of chaos in these systems [148]. In practical terms, it is best to use the Diny factor, the ratio of the richest part of a society to the poorest part of a society, as an indicator of the economic disparities in a society (Table 9.3) [128].

In a meta-economic approach to global population dynamics, there is no distinction between the developing and developed world; both are seen as constituent parts of a global system that are coupled by a common interaction. The differences in economic, historical and cultural development are absorbed in the model's generalised statistical approach because the global model deals with demographics as the sole expression of growth.

In developed countries with a stabile population like Germany and Japan per capita annual income is high and the distribution is more egalitarian. In the case of a rapidly developing county, like Brazil, the distribution is far from egalitarian. In Russia, the disparities are the result of an economic and moral crisis, the social injustice of an uncontrolled market, political chaos and the miscarriage of democracy after the collapse of the Soviet Union. China and India's remarkable rate of the growth and development unequivocally shows the validity of this approach. These numbers, however, should be interpreted in the context of demographic growth. From a basic point of view this is the real meaning of economic development, for what else is the economy, seen at large, but a global life support system.

The demographic transition in a large number of African countries is accompanied by wars, famines and mass migrations, illustrates the universal character of the demographic transition in a variety of economic, social and geographic environments. These countries are part of the global system and are all caught in the transition, even though they are much less socially and industri-

Table 9.3. Distribution of wealth in the world (1995) [118]

Region	Growth Rate %	GNP per capita ($ US)	PPP estimates of GNP per capita (current US $)	Ratio of household Richest 10% to poorest 10%	Income share Richest 20% to poorest 20%
World	1.4	6070	5 000	14.4	7.9
Developed countries	0.3	17300	12 300	15	7.2
Developing countries	1.42	3050	1 100	14.2	8.2
USA		27 000	27 000	15.9	8.9
Japan	0.2	22 000	40 000	—	4.3
Germany	0	20 000	28 000	8.4	5.8
Russia	–0.6	4500	2250	32	11.5
China	1	2920	620	10	7.1
India	1.7	1400	340	7.7	5.0
Brazil	2.6	2. 5400	3640	73	32

ally developed than other countries in the developing world. An in-depth study of this mismatch of development and the demographic transition is beyond the scope of this study.

It should be noted that developing countries spend more than $1 trillion a year on weapons, or $10,000 for every child born. These arms are a great menace: they are an economic burden; they are a danger to life and property; and they have an increasingly detrimental impact on the environment. Limiting armaments should be a high priority for these countries and for the global community. Small arms, like Kalashnikov's, other guns and land mines, have killed many more people than weapons of mass destruction, which somehow dominate the military minds of the developed world.

The cost of a modern war is enormous and the loss of civilian lives is many times higher than the loss of combatant' lives. Given the economic and environmental destruction that accompanies war, the fact that a war does not resolve most of the issues that caused it, demonstrates the total irrationality of modern warfare and the gulf between technology and mankind's ability to resolve its problems through reason and dialog. Africa, where mankind began its story, is currently torn up by local wars and a vast AIDS epidemic. It may even become a tragic continent of the world of the future, unable to catch up in social and industrial development with an exploding population.

9.7. Growth of a Knowledge Economy and Culture

The model equates the rate of growth to the development of the population system. It is a non-linear interaction and is not what would be expected in an economic system, which is usually assumed to be linear and additive. The interaction is multiplicative and irreversible and is the system's dominant feature, which determines, or rather moderates, the system's growth. The quadratic term expresses the contribution of the informational component to the global production factor. This can be seen as the primacy of the 'software' of global development, the component that is associated with culture, science and factors like co-operation, communication, consciousness and memory that constitute the generalised interaction.

In classical economic theory, growth and development are based on exchange in interpreting how the 'hardware' — industry and agriculture — works and generates wealth. However, after Max Weber and Josef Schumpeter, it is now acknowledged that 'software' is becoming the primary factor in development. Their ideas suggest that information is not a minor macroeconomic component, but the controlling factor in the meta-economics of a knowledge society. Francis Fukuyama notes:

> The failure to understand that the roots of economic behavior lie in the realm of consciousness and culture leads to the common mistake of attributing material causes to phenomena that are essentially ideal in nature [103].

This helps to explain the difficulties that were encountered in attempts to mathematically model long-term changes in the global economy by equilibrium models and neo-economic concepts. If the phenomenological theory can be interpreted in terms of the primary factors of economics, then the emergence of the quadratic interaction should become apparent. It could help reach a greater understanding of the phenomenology and lead to the construction of an economic theory, which incorporates the intellectual and cultural component of global development in an evolving network.

A major issue is how to treat intellectual property, and how it is generated, distributed and multiplied. The last point contradicts the very idea of property and the conservation laws in economics. If information is treated as an ordinary economic entity and exchanged like any other product in the market, its multiplicative nature and the irreversibility of its interactions are not taken into account. That is why extending the concept of property is inconsistent with the meaning of intellectual property. It should be recognized that if the production of basic knowledge is to be sustained, this should be done by other means and not by the market. For example, all great discoveries in fundamental science were traditionally placed in the public domain. The debate on placing the sequencing of the human genome in the public domain was an instructive episode in discussing these matters. Consequently fundamental research (and great art!) should be directly supported by society. With the growth of the knowledge economy these issues will have to be faced and resolved.

The demographic transition is the final stage of the quadratic growth process, a limit to the informational interaction that drove and moderated humanity's development up to the transition. Therefore, the limits to growth are internal and determined by the limits of the generalised 'software' of humanity's development. If the informational component of mankind's development determined growth in the past, it now has become the dominant 'limits to growth' factor.

Chapter 10

The World of the Future

Predicting the future is difficult,
for in most cases it is not easy to predict past.
Anon

10.1. Concluding remarks

The theory provides a description of the gross features of mankind's growth and evolution. Over the entire course of humanity's development, population growth has followed a self-similar pattern of growth, which expresses the dynamic invariance of development. The inherent limits for growth and the pace of history are determined by the mechanism of growth and development and not by resources or space. A simple and self-consistent mathematical model with a minimal number of constants provides a complete and quantitative description of the total human story. The crucial step was to identify the global population as a dynamic system that evolves by self-organization, based on a global informational collective interaction.

The interaction is proportional to the square of the number of people in the world as the outcome of an exchange of information that has been propagated and multiplied by a chain reaction throughout society. The exchange of information is both vertical (between generations) and horizontal (in space). It has synchronized the large-scale features of humanity's past since the appearance of *Homo habilis*, the tool-making man. The transfer of socially inherited information is a particular feature of humanity. It is a new factor of growth that is distinct from the genetically propagated information in all living and evolving creatures. This collective and co-operative interaction is responsible for the remarkable growth of human numbers and the rapid social evolution of humanity. Although, the essentially non-linear model's description of the process of development cannot be directly applied to local or regional growth the global process of development definitely influences all parts through the connections and interactions the model implies. Any part of the global system that is separated will inevitably lag in its growth.

A significant result from the phenomenological theory is the transformation of the effective time scale of history, a kinematic consequence of self-accelerated growth. The time scale of history expands as one goes into the past and corresponds to historians and anthropologists' intuitive insight. When the present is approached, the rate of growth and development becomes faster and faster and finally culminates in the population blow-up, which is abruptly cut off by the demographic transition.

The model indicates that mankind is now rapidly passing through a critical period and that the established pattern of growth and development is drastically changing. Humanity has been concerned with numerical growth in every aspect of life — children, food, housing, land, arms, power, etc. — for more than a million years. Now a fundamental change in the paradigm of growth is occurring. Some historians have pronounced this change to be the end of History. However, what humanity is experiencing is a much more profound transformation compressed into a remarkably short time of global change, when the time scale of history has merged with that of politics.

The demographic revolution is the most significant event in the history of humanity and far surpasses the Neolithic revolution and all other revolutions in terms of its importance and consequences. It is comparable to the emergence of *Homo* and only future historians and anthropologists will have the chance to really understand the magnitude of the transition humanity is to experience. They will only have to wait a hundred years to make their assessments, instead of the million years that have passed since mankind's origins.

When the global system passes through the demographic transition, the mode of growth radically changes and the old, established pattern of self-similar development is no longer sustained. The accelerating train of the global population system finally runs off the rails of hyperbolic growth when its speed of development cannot keep up with the population blow-up. The train derails, breaks up and has to rebuild and find a new route for growth and development. After this tremendous disruption, new forces of self-organization will begin to operate. Therefore, humanity is currently searching for unification, new informational ties and new structures. This process is now identified as globalization. Unsurprisingly, at this stage, disruptive and regional forces of a cultural, rather than an economic nature are growing and, at the same time, a blow-up in information technologies and a search for ideas and ideologies is seen.

This present period of rapid change is definitely responsible for much of the stress and strain of modern life, the great disruption now upsetting the long established patterns of social development. As for the numbers, the 'hardware' of our world is changing faster than the social conditions; the global 'software' has no time to keep up with the pressure of technological development. Consequently, a new set of values will emerge, expressing the change from quantitative growth to qualitative development. The nature of this imminent transformation is yet to be fully understood or have its consequences assessed. It is unclear if, in a world where numerical growth is decoupled from development, humanity will take up the challenge of qualitative growth or if it will evolve into a pattern of slow development that could potentially become stagnant and decay.

What long-term changes can be expected in the world as it passes into a new stage of development after the transition? By different methods, both demography and modeling show that the population of the world will rapidly stabilize at 10 to 12 billion, essentially doubling the current population and all growth will happen in the developing world. There are good reasons to expect that this ultimate state will be stable, although some large-scale social disruptions may yet occur and migration could substantially change the ethnic composition of countries and societies. The demographic transition is the final stage of quadratic growth, a limit to the informational interaction that drove and moderated humanity's development up to the transition.

Until now, global development has been moderated by information. Now it will be dominated by it. The future in post-industrial world will be determined by the 'software' of the population system and not by the 'hardware' — the production of food and energy. The difficulty at present is not the volume of production that matters, but the way the results of industry are distributed and used. In other words, the problem will not be the total outcome, the integral of the distribution functions, but how these distributions are realized in a global system. This is to happen at zero population growth and in a society dominated by older people. These in the first approximation are the boundary conditions for the future.

In this imminent future, the human capital of an educated society will be the decisive factor leading to the establishment of norms of social conduct. It will be determined more than ever by education and the attitudes and values propagated by the media. The media, especially television, has yet to recognize its responsibility for its influence on social capital and its attitude towards culture. In the past the church and religion took on the responsibility for propagating moral values and supporting art. Unfortunately, the media and those who control it do not fully recognize their duty to society, especially in terms of long-term commitments. At present the media are mainly concerned with their immediate commercial interests, and conspicuously lacking are the educational possibilities of the media.

In this study, the demographic factor is seen as the decisive factor. Until recently, the approach to global problems through demography was blocked by some parties and excluded from most of the international debate. Now this has changed. As these discussions excite high feelings on matters concerning our common future and the issues at stake are great, it is necessary to develop and foster interdisciplinary research that follows different intellectual traditions.

If this mutual understanding between the soft and hard sciences is reached, new problems and departures can be suggested for the theorist in making his constructs less abstract and more meaningful for the humanists. Here the quantitative data of demography have a special standing, as they are based on a universal measure for the growth and development of mankind expressed by population numbers and are directly amenable to quantitative studies. By definition, these studies are interdisciplinary because they involve different fields of knowledge.

10.2. Interdisciplinary Research and Demographic Policy

One of the main difficulties encountered in these studies is bringing an approach developed outside a particular domain of research into an established and traditional field of study, like demography, with its own well developed mathematical methods.

On many occasions these attempts are rejected to protect intellectual turf, but also because the parties concerned lack a real understanding of each other and a common aim. There are similar difficulties with interdisciplinary studies involving social sciences that rarely use models and quantitative methods aside from statistics. But statistics are only the raw material for a theorist when building a quantitative theory and going beyond the first steps in crude modeling. In these cases it is even more important to find points of contact and develop a constructive interdisciplinary dialog.

Much depends on the scale of human numbers. The scope of the field is most important: psychology mainly deals with individual behavior, sociology describes groups, history describes nations, and the phenomenological theory deals with humanity as a whole. The same reasoning applies to the change in the temporal scale from the human lifespan to millennia of history and a million years for anthropology. Integrative and phenomenological methods must compliment methods that act on a lesser scale to resolve problems of human nature based on a more detailed, sociological, approach.

A common object tends to unite different fields that are separated by incessant specialization. One must think in more general terms than those things that seem immediately responsible for what is appearing at first sight. This has occurred twice in the past: first when a heliocentric system was accepted. At that time, it had to be recognized first on a global scale, then on the scale of the Solar system, and finally of the Galaxy, that our world is but part of a greater Universe. It occurred again on a more human level when evolution gained acceptance and man became part of nature. Now we are confronted with global problems, which in a way pose the same difficulty in facing issues that are, as it seems to be beyond our command and even understanding.

Do we determine our future or are we yet at mercy of the statistical laws that govern our destiny? For example, one million people died on the highways in 2004. In the case of car accidents, most of what is happening is rather well understood and largely depends on our personal behavior and good will, but still it is difficult to change driving habits. Despite great efforts, the statistics of losses are fairly constant and the accident rate rises with the number of vehicles, though the relative number of casualties is slowly decreasing in some countries.

The probabilistic nature of the laws of growth, on which the model is based, and the sheer scope of events under consideration point to the basic nature of the causes of development. Therefore, it is difficult to imagine how the advances of science, medicine, social behavior and political will could, in a basic way, change the course of events, which follow statistically valid laws.

While this is a fundamental question and an issue that may be raised in the framework of this study, it is also something that will not likely be resolved within these deliberations. Can we really be objective or are we still anthropocentric in our understanding? Are demographic policies part of the systemic behavior of mankind, or have we, through our intelligence and knowledge, gone beyond the demographic system and attained a decisive influence on the destiny of our species? To some this attitude may seem scientistic and remote, fatalistic and lacking compassion and human understanding, but the point has to be made. On most occasions, much depends on the magnitude of events. At the scale of a single person, the freedom of decision-making and action is the greatest. The further we increase the numbers, the more the complexity of the systems involved will be determined not by individual decisions, but by laws of chance.

Methods developed in physics for describing the growth and evolution of open and evolving systems provide a common approach to the non-linear dynamics of problems in complexity studies. These methods should be seen not as receipt for solving complex problems, or a work-out for modeling, but rather as metaphors for our thinking. Now it may be expected that these methods can become instrumental in developing a theory of anthropology. It is to be hoped that these ideas may contribute to the analysis and projections of world population growth and the consequences it may have for sustainable development and global security. Last but not least this may help in developing an approach to controlling or rather guiding complex systems, in the first place human society, if not humanity at large.

10.3. Global Development at Large

This study mainly uses demographic factors to describe the state of the world. By making the dynamics of human numbers so prominent, the study emphasizes the singular importance of this main characteristic of growth. Demographic data has been used throughout this study to develop a non-contradictory and consistent quantitative theory that describes the gross features of our past and present.

Nevertheless, concepts from anthropology, history, economics and sociology can add further dimensions to these numbers and provide a socially relevant content, when the human side of growth and development — of wealth and misery — enters the analysis. It is important that the study includes this dimension because people generally ‘explain’ what is happening in socially significant terms of human behavior and motives. This can only be done, however, if an understanding of the grand design of history is reached and local and temporal events are reconciled with the dictate of the demographic imperative of the global interaction.

This point must be fully appreciated because the overall pattern of growth and the mechanisms driving it cannot be explained by reducing the complexity of development to a few, or even all, elementary processes that contribute to growth and development. All processes — for example, life and death statistics — are merely phenomenological generalizations at a level lower than that of quadratic growth. Even though partial generalizations may be useful in describing and studying these phenomena and perhaps even in assessing them a basic reductionist approach is beyond our means.

The interplay between a local and an overall treatment is especially important in economics, which provides a detailed and meaningful quantitative description of growth and development at a certain time. Major results have also been obtained using generalized methods, similar to Vasily Leontiev's input-output matrixes used to present a detailed balance of an economic system. However complete, this is only a snapshot of the state of the world, not a long-term description projected in time of the system's evolution. Long-term changes mean growth by orders of magnitude, not by incremental steps of a few percentage points a year. These basically linear methods can be used to work out the rate of local and instantaneous changes, but not the long-term trends. Following the same reasoning, demographic methods also only provide a detailed description of local and temporal changes.

In both cases, a piecemeal temporal analysis can be compared with long-term projections. Therefore, a detailed temporal analysis complements and enhances long-term projections rather than competing with or contradicting them. The complementary nature of both methods allows for a greater understanding of the real world. If the first method has a well-established tradition, but a short temporal range, the other was only recently developed, but has a larger scope. This raises a fundamental criticism of a general theory: does the theory really provide a new way of describing the human story or is it simply an exercise in applying rather far-fetched methods to describe the behavior of a complex and diverse system? It may be strange that abstract statistical methods are being used to describe a system that is so close to everyone. This question haunts any conscientious student of population growth and has been a challenge for me.

Cosmic changes in the Earth's orbit cause periodic climate changes like the rise and fall of the sea level as continental ice sheets advance and recede. Through migration, tribes and people carried languages and cultures throughout the world, and opened up and settled in new areas. Following economic and environmental impulses, civilizations grew and vanished, but growth of the global population, driven by the demographic imperative, was relentless.

Today, we are told that overpopulation, epidemics, AIDS, the destruction of the environment, crime, corruption, financial ruin and moral collapse threaten humanity. We are even told that an asteroid can hit the Earth, as it might have happened 65 million years ago. While these apocalyptic scenarios have some validity, it should be recalled that similar ideas have been prevalent since the appearance of world religions and eschatological doctrines. Moreover, these ideas spread and are amplified during crisis and change. At a time of crisis, man is acutely aware of his own frailty and mortality, and unintentionally projects these concerns onto humanity as a whole.

Scientists have discussed these phenomena and science is equipped to evaluate the potential threat and is ready to solve these challenges. If the necessary resources are mobilized, even an asteroid can be driven off its deadly course. Questions, however, still remain whether humanity has the common political will to act in the face of these dangers and if so, can it reach an understanding and properly assess the probability of averting the menace. These questions are not beyond the scope of modern science and technology. In terms of mankind's social software, however, these are global problems that humanity is poorly equipped to handle. Whether cultural development in its broader sense will become a major theme was raised in UNESCO's report *World Culture Report: Culture, Creativity and Markets* [128].

At the same time, the media and modern communications allow everyone in 'the global village' to be aware of local events no matter where they happen. This interconnectedness could lead to a new solidarity in facing disasters and common issues, but it could also lead to some issues being blow out of all proportion. Unfortunately this is a wide-spread practice in distorting the value of information.

There is a tendency to use this inter-connectedness to scare people and conjure up the next more frightening apocalyptic scenario. In these cases, a proper assessment can hardly ever be made because the public and government are overwhelmed by fear. The media, which often serves vested interests, exacerbates and multiplies these scares. For example, the Y2K affair — the supposed failure of computers on 1 January 2000, was definitely blown out of proportion by the media and the computer industry. In the summer of 1999, I attended Internet'99, an international conference in San Jose, California, the heart of Silicon Valley. During a tour of one of the largest software companies in the world and after a talk about future developments, I asked the vice-president for research, when we were for a moment alone, what he thought about Y2K. He candidly replied: 'it is a great hoax'. Today, it is clear that nothing really happened except for $200 billion reportedly being spent by the computer industry.

The results from modeling suggest that the entire concept is sound and that it provides a description of the real world. The model uses statistical averages that describe the demographic system in deterministic terms of probabilistic causality. Particular facts and events cannot be interpreted without taking into account their statistical relevance and origin. Although the theory only provides an approximate description of the world, which has infinite details that are relevant to sociologists and the public. In spite of its limitations, the theory brings together a host of facts and suggests explanations for many phenomena in the past, which is much closer to the present than usually thought. The theory also demonstrates the consistency of the statistics and invariance of the forces that drive humanity on its relentless course of growth. The theory decisively indicates the very special period mankind is currently passing through — the demographic revolution — and its place in a proper historic perspective.

The extent to which the past can be described determines humanity's chances in the future. Contrary to the subjective fears that mainly arise from a lack of understanding, this approach provides both a sufficiently complete description of the past and hope for a stable future for humanity. But can the theory offer guidance and perhaps a blueprint, if not a roadmap, for the future?

Some may believe that the stabilization of the global population is the result of proper demographic policies. These policies, conducted in tune with the natural trend of the demographic imperative, are a part of the demographic revolution. Recent events in developed countries already at the final stage of this transformation reveal features of a future world with a population that has leveled off. In a world with a stabilized population, numerical growth, primarily expressed by population growth, will no longer dominate. The connection between population growth and the population will cease to express development. At this point, there are two alternatives: developmental stagnation or a new dimension for development. With the loss of the quantitative growth of the past, the possibility for qualitative growth and development arises.

Most of nature and society develop through self-organization. Man has already directed the evolution of plants and animals to human needs, and now, with the advent of genetic engineering, science has provided powerful methods for molding new species. An ethical issue with far-reaching consequences that should be in facing our future recognized to what extent is interfering and accelerating human nature and society — going from slow self-organization to fast organization — possible and feasible. This issue raises deep emotions and scary visions, but these questions have come to stay.

Liberal economic conventional wisdom relies on the market as the main mechanism for growth and it certainly is a powerful force. As a self-organizing process, however, it has a short-term vision and any long-term commitments have to be directed by socially responsible forces. It could be suggested that the present reliance on the market is, to certain extent, the result of the collapse of long-term correlations during the demographic revolution. If this is the right interpretation of current developments, then globalization may indicate a new departure in long term organization, just as the European Union is an attempt to reorganize the political and economic space in Europe. But it may seem to be a fallacy of man's subjective judgment to believe that mankind is really in a position to control its destiny. As Italian economist Vilfredo Pareto notes, 'Human nature may be governed only by following it'.

10.4. The New World — Stabilized and Old

In the future, there will be a static population with practically zero growth. This future is supported by the model, which describes the transition from quadratic growth during Epoch **B** that culminates in the population explosion, and the most recent demographic projections. The invisible hand of self-organization at large is the collective agent that changes the paradigm of humanity's growth. The change is caused by a systemic crisis and is described by the asymptotic behavior of the model of the human population system.

The transformations induced by the transition will lead to a change in the age distribution and the values of society. The coming predominance of an old generation will place a heavy demand on social guarantees, medical services and pensions. The change in values will be expressed by a new set of attitudes between generations. In a static or very slowly growing world, much of the stress generated during the shock of the transition will be gone. Thus, there is a chance to rebuild the long-term connections of the extended family, which were disrupted during the transition as a way to regain the total fertility rate — the TFR. This could lead to an increase in the birth rate and stabilize society. It could even be conjectured that the current decrease in the TFR is a transient reaction to the stress and strain of the demographic revolution itself.

At present a low TFR is the main characteristic of post-transition populations. In all developed countries the TFR has gone down to 1.15 or less. For example, in Spain the TFR is 1.07 and in Italy — 1.12. This is a sign that demographically these societies are unable to support a constant population (TFR no less than 2.1–2.15). If these trends prevail, these societies are doomed and not because of a Malthusian lack of resources, but because of the prevalent values, cultural attitudes and priorities in developed countries. The only alternative is to change these artificial values, or perish being displaced by migrants with a greater fecundity. [See 105]. If this pattern will be taken up in developing countries in the near future, then mankind is heading for a major crisis, as our global demographic sustainability is challenged when the emerging post-transition society would be unable to reproduce itself, although this does not follow from the general premises of the model.

Migration, a major contributor to the internal dynamics of the global population system, presently sustains the gross population in developed countries. But the large influx of migrants can lead to lasting disparities that change the ethnic fabric of these societies, which find it all the more difficult to deal with the flux of migrants. On the other hand, migration does not contribute to the global population, but on a global scale is a stabilizing factor.

A detailed analysis of the stability of the global population system shows that after the transition in 2000, the global population system is inherently dynamically stable. This indicates that the future post-transition world with a constant population would be stable. In Epoch **C** the exponential time of growth becomes very long and loses its initial meaning. The concept of Time-2 will have to be redefined in this asymptotic state. The system will likely abandon the demographic cycles that occurred during Epoch **B** and develop another temporal structure. Once the population stabilizes, the connection between growth and development will have to change. Therefore, a new way to express and measure development will have to be found because it can no longer be expressed by numerical growth. Since numerical quantitative growth in other dimensions is limited, qualitative development remains. This is the meaning of the transition to a knowledge society. In this emerging world information technologies may become the decisive factors and the Internet is definitely a precursor of these developments. Another is the blow-up in communication due to the cell phone technology.

At present, the Internet is part of a global information interaction. In terms of the quantity of information, the Internet is certainly close to the ultimate global communication system. In producing and facilitating access to information, the Internet has created the opportunity and challenge in making sensible use of it. The real impact of this timely and remarkable development has yet to be properly evaluated and its impact assessed. The information media also demands a different and more powerful intellect to be gainfully used. By replacing rote and requiring a new way of training the human mind our educational technology has to take this into account.

The Internet is a self-organizing system, as well as a product of the global state of mind or perhaps a manifestation of global consciousness. It is possible that by of self-organization, the Internet, which is in the first stages of its development, could evolve into a system that has properties of consciousness, or at least its more primitive forms, like self-reflection. Its first reaction could be a critical appraisal of its content and traffic. This would require a selection process that is hardly possible at a stage when global self-consciousness has yet to evolve.

While discussing education policy in 1965, Russian psychologist Alexey Leontiev with great insight said that 'excessive information leads to an impoverished soul'. I would like these words to be seen on every site of the Net! Information pollution is one of the problems now facing humanity and is exemplified by the redundancy of advertising and the low, if not abysmal, standards of the media and much of the Internet itself. In fact, modern society can be described as a conspicuous information consumer society.

Huge amount of information are processed by people not for education and enlightenment, but as totally useless or irrelevant information. It satisfies primitive instincts in advertising, gambling, or entertainment, and acting in a way very much like a narcotic in our brave new world. Perhaps this could be traced to stimulating neuro-physiological circuits and hormones having nothing to do with the reasonable existence of *Homo sapiens*. This is becoming a social issue of growing magnitude and should be seen as one of the factors limiting progress and development, as a paradoxical result of the demographic revolution and information explosion.

The changes in governance and social coherence in the world illustrate the disparities generated by the demographic transition. The acceleration of history, which reached its maximum during the transition, can be seen in the decay of most of empires and large scale imperial structures. The Spanish, the Ottoman, the Austro-Hungarian, the British, the French and finally the Russian and Soviet empires have all disintegrated. It even may be suggested that the fundamental reason for these great changes could be traced to the criticalities of the demographic revolution, as a phase transition, similar to melting, to the loss of coherence in space and time. At present only China and India have retained their integrity. On the other hand the experience of the rapidly expanding European Union is of increasing significance for the world as an example of a novel process of organization (or self-organization?) on a continental scale.

There are many examples of small-scale spontaneous developments, which are new forms of self-organization. For example, the great multiplication of NGO's and the fragmentation of governance and even decay leading to corruption and the growth of organized crime, for is not the Mafia also an NGO? On the other hand these happenings may be a process of reorganizing society and building a civil society of our future from the chaos triggered off by the demographic transition.

George Soros in *The Crisis of Global Capitalism* discusses the issue of the chaos and self-organization of the market, which is opposed to the socially oriented plans of a central government [130]. Especially concerning is the apparent lack of broad cultural ideas and concepts. This deficiency is evident in socially relevant ideologies, religion and even in science. The retreat to fundamentalism in religion has become a common pattern in recent developments and may be a reaction to change by traditional established systems.

The work force in developed countries has made a significant shift from production to services like health, education, science and leisure. Modern industry's productivity is high. For example, it takes ten working hours to produce one medium-sized car. However, in 1999 the turnover in Germany's information sector became greater than in the motor car industry, traditionally one

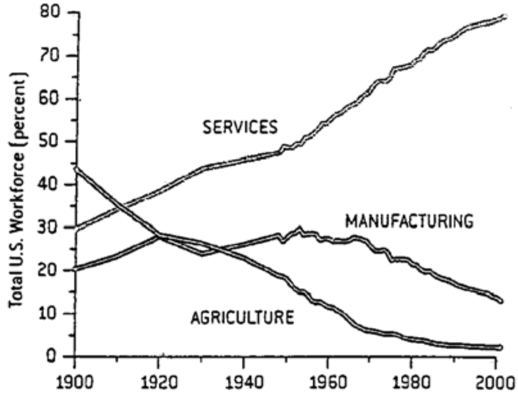


Figure 10.1. Deindustrialization: Changes in total U.S. work force in 20th century («Scientific American» October 2002)

of the pillars of German's economy. A remarkable development is the explosive growth of the software industry in India, exporting more than $25 billion in 2004, showing a new division of labor in the world.

Of special concern is the change in the work-force in the modern world and the growing disparities in the developing and developed countries in spite of the rate of development, now happening world-wide. These challenges may be seen in many other processes when rapid changes are happening in long-established industries. Often the demands of restructuring are so great that society and economy cannot keep up with the pressure and modernizing the industry is mostly limited by social, managerial and financial reasons rather than technology. For example, this has led to conflicts in Russia and Britain's mining industries.

The epoch of numerical growth is coming to an end. Epitomized by the multiplication of human numbers, of wealth, power, capital and guns, in megatons, gigawatts and teraflops, mankind has hit a limit and now we all see the slow and painful transition to a new social order. A state of emergent structures breaking through the disorder of the global demographic revolution, which, like all revolutions in its beginning generates chaos.

In *Caring for the Future: Making the Next Decades Provide a Life Worth Living,* it is argued that the principle aim of development is improving quality of life [125]. The report was published in 1996 and written by the Independent Commission on Population and Quality of Life, chaired by former Portuguese Prime Minister Maria de Lourdes Pintasilgo. The report supported the Brandt report, *North-South: a Program for Survival*, and Gro Brundtland's report on the environment, *Our Common Future* [113]. Brundtland's report explicitly states: 'We need a transition from quantity to quality'.

Caring for the Future was probably the first report to examine population growth and development together. The report is based on extensive interviews and the work of *ad hoc* international study groups presenting a cross section of the global state of affairs. The report analyses the population challenge and focuses on a holistic approach to population policies. The goal of development is a sustainable improvement of the quality of life while respecting the environment and human rights. Finally, the report focuses on policies regarding population and the necessity of developing another mode of development and a social contract based on a new set of values.

Equity is the most important issue for the future. The report correctly places equity higher than sustainability, because without equity there can be no security. In the report, 'equity' has a broad meaning that includes equity of individuals, institutions and states. The report's political recommendations are targets and timetables for improving healthcare and education standards throughout the world. Women's rights are placed at the forefront of the effort to stabilize the world's population, but this issue should be considered in light of the fact that the lifestyle in modern developed countries is demographically unsustainable. It should be noted that the authors reject an over-reliance on free market economics, which condemn sections of the world to poverty, ill health, and underemployment.

The report advocates a tax on international financial transactions to produce the necessary funding for these global policies. The report fully recognizes the demographic transition and the change in attitudes and values it will bring about. The report emphasizes the necessity of gaining an understanding of these global issues because these problems can only be resolved through stronger socially oriented governments and the emergence of global governance.

Finally, the report argues that there are enough resources in the world to sustain a decent quality of life for all. In terms of energy, the authors recommend limiting atmospheric pollution, changing industrial technology, altering man's energy demands and encouraging energy saving measures. The report provides a socially relevant content to the rather formal, if not mechanistic, constructs of the phenomenological model. The theory, on the other hand, can offer a medium in which to place the social and economic message of the report. The report outlines a positive future and in no way shares the apocalyptic pronouncements of latter day Cassandra's.

Much depends on whether mankind can produce the appropriate culture and science in the future. Since the days of Galileo and Newton, modern fundamental science has become global, not being geographically or linguistically limited. Indeed, the language of science shifted from Latin to French to German and to now to English as the scientific centre of the world moved from one country to another. Science has become a significant sector in the knowledge economy and innovation both because of the sheer number of people involved and the huge amount of investments. During the golden age of science, fundamental discoveries were made using rather primitive means. Today, most experiments require a great effort. International laboratories and cooperation are common practice in space sciences, astronomy, nuclear physics, biotechnology and other fields of advanced modern research. Despite the tremendous volume of research, many observers note that most efforts are directed at developing lines of study set forth at the beginning of the 20th century. The highest expectations are in modern biology, but even this field originated in the 19th century.

Many note that with the expansion of pragmatically oriented work, the number of fundamental discoveries is low in comparison to the great creative explosion, which took place a hundred years ago. While a comparison between the two periods is difficult to make, the scope and influence of Nobel Prizes can be a common indicator.

If the rapid blow-up of population and development in Europe a hundred years ago provided for the remarkable progress in science and technology, then can a similar effect be expected in the East? The great extent to which science is supported in China may lead to a new breakthrough in sciences, as many Chinese have been trained in US, Russia and Europe and can now contribute to the scientific development of their country and globally.

The dominant trend in both the natural sciences and the social sciences is further specialization. Former US National Academy of Sciences President Frederik Seitz has written about the growing difficulties interdisciplinary research faces [162]. This is especially unfortunate because the social demand for studies on major social and scientific problems, which could potentially offer guidance and advice, is high during times of change.

In closing, the following remark by President of the Royal Society Lord May can help in assessing the need for these studies:

> It is interesting to speculate whether the denizens of other inhabited planets — if there are any — share the vagaries of our intellectual history, a fascination with the fate of the universe and the structure of the atom, lagging well behind is the interest in the living things with which we share our world.
>
> A different but related question lies in human institutions, difficulties in taking action to address long-term problems at the expense of short-term interests (witness climate change). Such questions do not come readily under Medawar's rubric of science as 'the art of the soluble', but they go to the heart of humanities future, which unwittingly entrains the rest of life on Earth [45].

Some observers noted the erosion of science's moral authority and credibility, difficulties in producing objective expert opinion. This is of special significance in planning large scale projects, which are in need of interdisciplinary advice. For example, environmentally sensitive issues, nuclear energy, projects in modern arms and military high technology are of concern.

A crisis of rationality is spreading and the public mind is shifting towards irrationality, which leads to the growth of mysticism and religious fundamentalism, the rise of antiscientific and pseudo-scientific trends. On the other hand post-modernism is deconstructing the whole edifice of science. Are these signals of a loss of continuity in intellectual and cultural traditions because of the rate of change during the demographic transition or is humanity facing a long-term trend towards the slowing down of global development?

It can be expected that in the future armies will change. There are not enough people in countries that have passed through the transition to man the huge armies of the recent past by conscription. While low growth rates and stagnant populations do not create conditions for conflict and world wars like in the past, science and technology have changed the character of modern warfare. The mission of these new armed forces could change from large-scale operations intended to achieve territorial gains and a new world order to maintaining peace, fighting terrorism and organized crime, and policing the world. These recent changes present a challenge because the military is generally a conservative body and is slow to restructure. Nevertheless, the last sources of a large-scale conflict are the countries just entering and passing through the demographic transition.

The experience with modern armed conflicts time and again shows both the arrogance of power and futility of war in terms of its impact on history. On the other hand, the power of the instruments of persuasion, of the mass media in the first place, to the extent that psychological warfare is often more productive than direct intervention. In briefly considering these complex matters it can only be noticed that the social software in becoming of greater importance that the hardware, in whatever way it is accounted for by the dogmas of religious fundamentalists or the persuasive power of television. At this point Bismark's remark that the Franco-Prussian war was won by the German schoolteacher is worth recalling.

Federico Mayor, former UNESCO Director General, proposed the idea that in the context of the changed role of armed forces, the transition from a culture of war to a culture of peace should be considered [123]. In a world with a stabilized global population and an altered age structure, the concept of a culture of peace is not simply a humanistic initiative. These new conditions are becoming an objective factor and could be expressed in a new set of values and principles for international conduct. The new values and principles should exclude the possibility of large-scale conflicts and develop dialogues instead, which could contribute to a demilitarized world.

After the 1992 International Conference on Development and the Environment in Rio de Janeiro, the idea of sustainability gained ground. It was developed in the Brundtland Report and defined as 'meeting the demands of the present without infringing the rights of the next generation in satisfying its demands'. The concept of sustainability should be seen in connection with the demographic imperative as the primary political responsibility towards the coming generations and at this stage the role of responsible democratic governance becomes a crucial issue at the time of a global crisis.

The developing world is experiencing rapid economic growth, urbanization and growing regional tensions from wealth and poverty. It is difficult to expect these countries to follow the demands of sustainability and change their pattern of development in energy and their impact on the global environment before they get through a phase of extensive development during the demographic transition.

History unequivocally demonstrates that the growth of population had precedence over the environment, although some civilizations did perish with the collapse of the environment as it happened in Mesopotamia. Then people moved to and resettled in other parts of the world in search of space and resources. The distribution of global resources rather than a lack of them create the disparities and misery. In a stabilized world with a slow rate of development, a new ecological consciousness that includes outspoken criticism of consumerism could develop. On the other hand, the low TFR is what matters most for the future.

In 1990, the World Resources Institute, which was founded by Nobel Prize winner Murry Gell-Mann and others, indicated that humanity was facing:

1. A *demographic* transition to a roughly stable global population.
2. A *technological* transition to a minimal environmental impact per person.
3. An *economic* transition to a world in which serious attempts are made to change the real cost of good and services — including environmental costs — so that there are for the world economy to live off nature's 'income' rather than depleting its 'capital'.
4. A *social* transition to a broader sharing of that income, along with increased opportunities for non-destructive employment for the poor families of the world.
5. An *institutional* transition to a set of supranational alliances that facilitate a global attack on global problems and allow various aspects of policy to be integrated with one another.
6. An *informational* transition to a world in which scientific research, education, and global monitoring allow large numbers of people to understand the nature of the challenges they face [153].

Global warming and climate change are not fully understood. Recent results about the climate of the past, the most exhaustive of their kind, show the complexity of the global climate system. The climate system is highly interactive and non-linear. This characteristic is seen when the driving force of changes in insolation is compared to the resulting changes in global temperature and climate (Fig 4.3). At present the Earth is at the high point of a cycle, and it is difficult to assess the effect of human activities on the climate. It may be that the warming is a natural trend after the last ice age and later the climate will enter a long phase of global cooling.

Enforcing changes in the global energy policy is difficult because the world's understanding of the issues is insufficient and there is a lack of political will on a regional and international level. Countries like Russia and Canada could even gain from global warming. Nevertheless, it is difficult to imagine rapid climate changes in the next 50–100 years, when the global population system will complete its transition. Given the remarkable resilience of the population system, it is unlikely that humanity's future will be impaired by unduly upsetting the climate system.

At this point, it is proper to inquire what could be the next step in the evolution of mankind. Up to the present, the biology of the human race has not changed and was determined by nature. Now there is a possibility for man to interfere with and moderate biology, the genetic make-up of mankind, because humanity itself can be a conscientious actor. These factors could potentially alter the model and, at the same time, indicate the agents for change that could ultimately set a new dimension for the development of mankind. In this case, we are to step beyond the limits set by the model, as its premises will no longer be valid.

The largest changes in the future may be the consequences of recent discoveries in biotechnology and direct intervention in the human genome. The unraveling of the human genome could potentially lead to man's ability to modify his genetic inheritance, which could change human nature and, hence, mankind's destiny. In terms of the model, it means changing the value of the constant K, a number related to the complexity of the human mind. Is mankind morally ready to accept such interference with human nature?

The Internet and the human genome demonstrate the importance of information at the current stage of humanity's development and Nobel Laureate David Baltimore described modern biology as an information science. In other words, evolution has led to the appearance of human intelligence. The Faustian dilemma facing everyone is that mankind is ultimately stepping into the new age where intelligence could potentially change human nature and evolution. Mankind will be governed, challenged and limited by the informational nature of its development and, hence, the quality of human capital.

During the Great Depression, Keynes sent a message:

> Suppose that a hundred years hence we are all of us eight times better off than we are today... Assuming no important wars and no important increase in population, the economic problem may be solved... This means that the economic problem is not — if we look into the future — the permanent problem of the human race.

> Why, you may ask, is this so startling? It is startling because — if instead of looking into the future, we look into the past — we find that the economic problem, the struggle for subsistence, always has been hitherto the primary, most pressing problem of the human race — not only of the human race, but of the whole of the biological kingdom from the beginning of life in its most primitive forms.
>
> Thus we have been expressly evolved by nature — with all our impulses and deepest instincts — for the purpose of solving the economic problem. If the economic problem is solved, mankind will be deprived of its traditional purpose.... I think with dread of the readjustment of the habits and instincts of the ordinary man, bred into him for countless generations, which he may be asked to discard within a few decades.
>
> To use the language of today — must we not expect a general 'nervous breakdown'?...Thus from the first time since his creation man will be faced with his real, his permanent problem — how to use his freedom from pressing economic cares, how to occupy the leisure, which science and compound interest will have won for him, to live wisely and agreeably and well...
>
> There are other changes in other spheres to which we must expect to come. When the accumulation of wealth is no longer of high social importance, there will be great changes in the code of morals. We shall be able to rid ourselves of many of the pseudo-moral principles, which have hag-ridden us for two hundred years, by which we have exalted some of the most distasteful human qualities into the position of the highest virtues... The love of money as a possession — as distinguished from the love of money as a means to the enjoyments and realities of life — will be recognized for what it is, a somewhat distinguishing morbidity, one of those semi-criminal, semi-pathological propensities which one hands over with a shudder to the specialists in mental disease.
>
> But beware! The time for all this is not yet. For at least another hundred years we must pretend ourselves and to every one that fair is foul and foul is fair; for foul is useful and fair is not. Avarice and usury and precaution must be our gods for a little longer still.

These words by the great economist on the *Economic possibilities for our grandchildren,* taken from *Essays in persuasion* and written in 1933 are addressed to us, should come as an appropriate ending to a chapter on the future of mankind [86].

In the first place energy production has just passed the limit set by Keynes. But are the changes that he predicted coming with the demographic revolution and its shift from a power driven economy to an information dominated society? It is also no accident that, in these prophetic words, a change of values is indicated to be of primary importance.

In the world of the future, education will continue to require more and more time and engage a growing number of people. In developed countries in terms of human resources education at present is taking up more time and effort comparable to that of productive work. But the quality and intensity of the output fully justifies the expenses in training and the resources necessary for education. Thus the education sector in a modern economy is larger than in agriculture and the food industry and comparable to the production sector. The growing amount of time required to educate a member of society is a direct expression of the information crisis and indicates that humanity is definitely close to its capacity to train and educate the next generation At this point the remark by the writer and president of the Czech Republic Vaclav Havel 'The more I know, the less I understand' is an important reminder of the real meaning of education. In a world flooded by information understanding becomes the aim and critical feature of education. That is why the efficiency of education has become a matter of growing concern, for it may limit our development to a greater extent than the efficiency and productivity of the energy sector.

In a world where globalization has become an imminent and dominant feature, the opposing trend of cultural diversification is apparent. This may lead to a major confrontation between the 'hardware' of civilization and the 'software' of culture. This 'clash' has always been present in mankind's growth and development, and terrorism is one of the signals. Today, these strains and inequities could result in major conflicts in rapidly developing countries and massive migration from the developing countries to the developed ones. This is the opposite of what happened in the 19th century, when migration mainly from Europe was directed to the colonies.

On one hand, in the future we can hardly expect to sensibly influence and change the overall pattern of growth. Given the sheer size of the global population and the rate of events, it is difficult to imagine how the world community can have a major effect on the population imperative with a pronounced lack of global governance and political will. On the other hand the fundamental understanding of growth is still rather limited and, apart from the very general recommendations that lead to the current demographic policies, definitive advice for action is hard to provide. Probably, one issue of overwhelming importance is to ensure the stability and security of the world to be because this is the prerequisite for resolving global problems and facing our common predicament. However, as another overwhelming issue, this requires a world that takes care of the environment, social equity and balance between cultures. In short, this requires an orientation towards sustainability, building on recognized ethical principles in the sense of a world ethos and of intercultural humanism. Presently, the activities for an eco-social global market economy and, particularly, for a Global Marshall Plan/planetary contract, seem to have a potential to lead us in this direction. Consequently, this book is a Report to the Club of Rome but also addressed to the Global Marshall Plan Initiative.

Summing up the principal result of this study is that our growth and development is mainly determined by the human capacity to obtain, store, multiply, transmit and use knowledge. All through the ages it determined the persistent and systemic growth of human numbers. Now we have hit our intellectual and even the ethical limits to growth. It by far supersedes the limits imposed by other resources, which conventionally have been seen to be the limiting factor. As in all complex problems any statement cannot and should not be exclusive. But at present it seems that time has come to consider the very special capacity of humans that has made us both so powerful and numerous to look into the cause for the changes challenging our development both in numbers and reason.

Appendix

The Mathematical Theory of Global Population Growth

> In complicated matters common sense should follow the results of calculations. Formulae do not disclose subtle differences, but they are easier to handle.
>
> ***Emil Borel***

A.1. The Demographic Problem

The main objective of this chapter is to present the demographic problem in mathematical terms. The treatment will be as simple as possible, without sacrificing the meaning and content of the problem. At the same time, it will not attempt to make generalisations, which tend to hinder rather than help analyse growth. The main point is to focus on the physics of demographic growth, discussed in the first chapters, and then to find the appropriate mathematical concepts to express these processes. In this, the methods and tradition of theoretical physics will be followed, rather than the proofs sought by the more disciplined mind of a mathematician. For a general approach to these problems, there is an extensive body of monographs and textbooks treating this rapidly expanding field of many-particle physics, non-linear mechanics and synergetics [138,141,143,146,151,152,154,156 and 158]. For an extensive review of finite time blow-up phenomena, see [157, 164].

In developing this approach, one has to keep in mind both the complex nature of the demographic system and the often subconscious subjective desire to offer immediate explanations by obvious and seemingly meaningful explanations, which complicates these studies. The subject of life and death, procreation and the size of the population deeply engage any student of human affairs and make it difficult to remain sufficiently detached from these issues. This leads to an often involuntary urge for reductionism, i.e., suggesting partial explanations that have no real value and are unlikely to help reach an understanding. In keeping within a systems approach, much of the final treatment may seem paradoxical confronting conventional wisdom when the general and somewhat remote laws are sought.

The population of the world at any given moment of time *T* will be characterised by a function *N(T). N* is an additive variable and is the only one taken into account to describe the global population. All other variables — the distributions of population in countries, towns or villages, by age and sex, by income, etc. — are not taken into account in the first approximation. This is the outcome of the slaving principle that Herman Haken formulated in synergetics. At this point it should be mentioned that the term 'slaving' is probably inappropriate in the context of demographics. The senior variable and the parameter of order is *N*, and all other variables are subordinate to it. In regard to the demographic problem, this corresponds to and is an expression of the principle of the demographic imperative, which was introduced when these issues were discussed.

The idea of singling out the principle variable is based on asymptotic methods, which are used to solve problems of great complexity. In this case, all secondary variables are averaged out in order to obtain an abridged equation of growth and retain only the senior variable $\mathcal{N} = \overline{N}$, averaged in time. This is a significant simplification, as all rapidly changing variables are excluded and, in the 'short' equation only two variables *T* and *N* are left:

$$\frac{\partial \mathcal{N}}{\partial \mathcal{T}} = \overline{F(N,T,X,Y,\tau,\nabla^2 N,\ldots)} \rightarrow \frac{dN}{dT} = f(N,K,\tau) \qquad \text{(A1)}$$

where *K* and τ are scaling factors for population and time.

This exclusion of all other variables — spatial and internal systemic variables — has become one of the main ideas in dealing with non-linear problems and, as a result, asymptotic methods are now widely used. Like all approximate methods, they have limits, which are set by the nature of the problem.

In the demographic problem, asymptotics means dealing with changes in time longer than the period of a generation. It can then be assumed that the duration of a lifetime will not explicitly enter into the formulas and that the changes in age and sex distributions and all other rapidly evolving social and economic variables will be irrelevant. These details can only be accounted for in the next approximation by first bringing in the reproductive period and the finite human lifetime.

In dealing with systems dynamics in a system with many degrees of freedom where many factors affect growth, it may be assumed that this multitude of processes can be treated statistically and that the nature of these statistics does not change. It can then be assumed that systemic growth will be self-similar and, as a consequence of dynamic self-similarity, scale. This main hypothesis can be expressed mathematically by stating that the relative rate of change in the demographic system is constant:

$$\lim_{\Delta N,\Delta T\to 0}\frac{\Delta N}{(N-N_a)}\frac{(T-T_b)}{\Delta T}=\frac{d\ln|N-N_a|}{d\ln|T-T_b|}=\alpha \qquad \text{(A2)}$$

where N_a and T_b are the reference values for population and time. In most cases $N_a = 0$ and N is always positive. The expression means that self-similar growth is necessarily described by a power law:

$$N=C(T_{1,0}-T)^{\alpha} \qquad \text{(A3)}$$

C and α are constants, and time is reckoned from $T_{0,1}$.

In self-similar growth, the ratios of the change of time and population are constant. But this self-similar pattern of growth is not unbound and can occur only within certain limits. These limits are set by the discrete nature of population: the growth rate cannot be made less than one person per generation and by changes in the shortest unit of time — the length of a generation. The simplest case of self-similar development is linear growth, when $\alpha=1$. In the framework of the model, this corresponds to the initial stages of development. During Epoch **B,** a different law of growth — hyperbolic growth — is valid, with $\alpha=-1$.

The 'short' equations are asymptotic and, as statistical averages, describe self-similar growth. In other words, not only averaged numbers but also statistically averaged functions are dealt with in treating growth and development. The physics of gases is a good example for the kinetic theory of gases is a well-developed field in theoretical physics, and as a classical many-particle system, gases provide useful analogies for population studies. In thermodynamics, the phenomenological, macroscopic parameters of a gas are its temperature, pressure and density. In the kinetic theory of gases, pressure is seen as the result of the average motion of all kinds of molecules, which are not treated individually. For example, the momentum for each type of molecules is summed up and averaged to work out the pressure.

In an ideal gas, all states are self-similar and, in this case, there is no specific volume, pressure or temperature. Indeed, the gas laws are a simple proportion that is intuitively easy to understand. For example, by doubling the pressure, the density of a gas doubles. When heated at a constant volume, pressure follows the absolute temperature; therefore, the gas laws scale. However, if the finite size and the interactions of molecules are taken into account, as is done in the theory of a non-ideal gas, the limits of the asymptotics of the ideal gas equations of state may be determined. This is done much in the same way as the finite human lifetime sets the limits for the asymptotics of hyperbolic growth.

In the Van der Waals model of a non-ideal gas, a phase transition occurs at certain temperatures (and pressure), just as the demographic transition happens at a certain time in the case of population growth. In thermodynamics and the dynamics of population growth, temperature and time are the parameters that determine the changes of these systems. One system is closed and in equilibrium, while the other is open and evolving. The non-ideal gas model is relevant in yet another way: the Van der Waals interaction sums all binary interactions between molecules and is proportional to the square of the density, the square of the number of particles in a given volume. In other words, it is similar to the collective interaction introduced to explain the growth of human numbers. In the first approximation, this interaction is proportional to the square of the total number of people on a finite Earth, regardless of their detailed distribution and specific nature of the interaction.

A.2. The Case of Quadratic Growth

The first step to solve the demographic problem is to find the appropriate description of the global population system's growth, which is similar to the equation of state for an ideal gas. This was done by a number of authors, and according to Nathan Keyfitz, McCormic was the first. Then, in 1960, American engineer Von Forster suggested an empirical formula (A3) where the constants:

$$C=(187\pm0.4)\cdot10^{9},\ \ T_{1,0}=2027\pm5,\ \ a=-0.99\pm0.09$$

were determined by a least square fit to population data since 1 CE. Although the accuracy is overestimated this result indicates the robustness of hyperbolic growth. Von Horner in 1965 suggested a similar expression when discussing the possibility of dealing with the run-away population explosion by escaping from Earth for other worlds:

$$N = \frac{C}{T_{1,0} - T} = \frac{200}{2025 - T} \text{ billion} \tag{A4}$$

where $a=-1$. This expression describes the growth of the global population over a very extended time [52]. I obtained this equation independently and treated it as an asymptotic equation that describes self-similar growth, limited in time, right from the beginning. This was a decisive step because it allowed the human lifespan to be introduced as a limit to the asymptotics. The need to take into account the limits of asymptotics in scaling was discussed in detail by Bahrenblatt [140, 159] and Umpleby suggested that (A4) could lead to a paradigmatic revolution in demography by requiring an extension of the temporal scale for describing growth [60].

A.3. Defining the Model and Excluding the Singularities

The goal is to establish the limits of scaling in equation (A4). In the first place, the maximum rate of growth has to be limited at the onset of the demographic explosion, when the population enters the demographic transition, because an increase in the population during an effective generation cannot be expected to exceed the global population. At the other extreme, at the very beginning of development when N is small, the growth rate cannot be less than one person, or rather a hominid, per generation. A similar limit is introduced at the initial stages of bimolecular reactions in chemical kinetics to postulate growth and get the reaction started. In demography, these conditions are:

$$\left(\frac{dN}{dT}\right)_{\min}\Bigg|_{\substack{N\to 1\\ T\to T_0}} \geq \frac{1}{\tau_0},\ \frac{1}{\tau_1} \geq \left(\frac{1}{N}\frac{dN}{dT}\right)_{\max}\Bigg|_{T\to T_1} \qquad \text{(A5)}$$

and indicate that the limits in (A2) cannot be reached, because the continuity of human numbers is limited by integers to one person appearing during τ_0 and time — by the intrinsic limit τ_1. Thus, the inequalities (A5) set the limits of scaling. The first limit is valid for the initial stages of development and has a dimension [time $\times$ people]. The other limit is valid for the present and the dimension of τ_1 is time. Two values for τ could be used, but anthropological data shows that if both are equal $\tau_0 = \tau = \tau_1$ this leads to a very plausible estimate for the beginning of anthropogenesis T_0 = 4.4 million years ago.

The final equations for the growth rates are obtained by adding the term $1/\tau$ to the expression for quadratic growth. To introduce a cut-off during the population explosion, a τ^2 term has to be added in the denominator to exclude the hyperbolic singularity

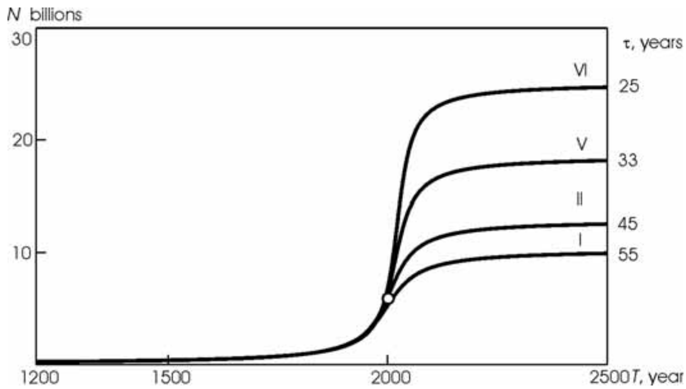


Figure A1. Model of global population growth for different values of the time constant τ ◦ – 6 billion at $T_1 = 2000$

during the population transition:

$$\frac{dN}{dT} = \frac{N^2}{C} + \frac{1}{\tau} \quad \text{(A6a)}$$

$$\frac{dN}{dT} = \frac{C}{(T_1 - T)^2} \quad \text{(A6b)}$$

$$\frac{dN}{dT} = \frac{C}{(T_1 - T)^2 + \tau^2} \quad \text{(A6c)}$$

When these equations are written in a dimensionless form, it will become clear that the terms added are of a similar nature. By bringing τ into the equations of growth, the human lifespan is introduced as the microscopic parameter of the theory that sets the limits of growth in the past and regularizes the divergent growth during the population explosion at T_1, a time close to $T_{1,0}$ once the divergence is excluded. Growth can then be extended into the future, past the critical date. The constants appearing in these equations may be determined by integrating (A6c):

$$N = \frac{C}{\tau}\cot^{-1}\left(\frac{T_1 - T}{\tau}\right) \quad \text{(A7)}$$

and then fitting the equation to the population data that describes the global population transition. A set of paths, describing the

Table A1. Systems constants for different models

Model	N_∞, 10^{-9}	C, 10^{-9} years	τ, years	T_1 year	$\left(\frac{dN}{dT}\right)_1$ 10^{-6}/year	$\frac{1}{N}\left(\frac{dN}{dT}\right)_{max}$ %
I	10	180	55	1998	60	1.31
II	12	173	45	2000	86	1.61
III	14	186	42	2007	105	1.73
IV	15	190	40	2010	119	1.81
V	18	195	33	2017	180	2.18
VI	25	200	25	2022	320	2.88
VII	∞	200	(20)	2025	—	—

Model	T_{max} year	N_{1990}, 10^{-6}	$T_{0.9N_\infty}$, year	K,	T_0, 10^{-6} years	$P_{0,1}$, 10^{-9}
I	1964	5260	2157	57 200	4.9	99
II	1981	5277	2136	62 000	4.4	95
III	1989	5253	2138	66 600	4.4	103
IV	1993	5259	2133	68 900	4.3	106
V	2003	5230	2119	76 900	4.0	110
VI	2011	5306	2009	89 400	3.5	114
VII	—	5713	—	(100 000)	(3.1)	115

transition with parameters listed is shown in Table. A1. The best fit is Model II with the following parameters:

$$C = (173 \pm 1) \cdot 10^9,\ T_1 = 2000 \pm 1,\ \tau = 45 \pm 1,$$

$$\text{and } K = \sqrt{\frac{C}{\tau}} = 62000 \pm 1000. \qquad (A8)$$

The magnitude of τ is determined by the passage of the global population through the demographic transition near T_1. In practical terms, this occurred at the onset of the demographic transition after 1955. If τ is critically dependent on the global population transition, calculations show that T_0 does not significantly depend on the time constant τ.

It is useful to deal with the absolute growth rate (A6c) and the relative rate:

$$\frac{1}{N}\frac{dN}{dT} = \frac{\tau}{\left[(T_1 - T)^2 + \tau^2\right]\cot^{-1}\frac{T_1 - T}{\tau}} \qquad \text{(A9)}$$

that reaches its maximum value 1.6% per year at $T_{max}=T_1-0.43\tau$, in 1986, not taking into account a short time of post-war growth from 1950 to 1970. The relative growth rate at T_1 will pass the high point of absolute growth:

$$\left(\frac{1}{N}\frac{dN}{dT}\right)_{\max} = \frac{72.5}{\tau}\,\%\ \text{per year}, \qquad \text{(A10)}$$

which is less than (A10) and reached 1.4% in 2000. In the rapidly changing circumstances of the demographic transition, the maximum for the relative growth rate, expressed in percent per year, precedes the high point for the absolute growth rate. In terms of the global demographic transition, the difference is $0.43\tau = 20$ years. During the demographic transition from $T_1-\tau=1955$ up to $T_1+\tau=2045$ the global population will, on the average, grow by 2%, or:

$$\frac{\Delta N}{\Delta T} = \frac{\pi K^2}{4\tau} = 67\ \text{million}, \qquad \text{(A11)}$$

not taking into account third order terms. The maximum growth rate $K^2/\tau = 86$ million per year is reached in 2000 and recent UN data are shown in Fig. A2. The critical hyperbolic run-away time $T_{1,0}$ = 2025 is shifted to T_1 because of the splitting of the singularity in 2025, when a finite width of the population transition is introduced, an effect to be expected when regularizing growth.

These calculations are based on revised 1998 global data parameters (A8) used for the Model in this the book and are presented in Table A1. These revisions do not change the principle result for an envisaged stabilization of the world at 10 to 12 billion.

Table A2. Models for global population growth (in millions)

Year	N, m	I	II	II	IV	V	VI	VII
1750	728	712	685	714	721	722	727	720
1800	907	884	851	883	890	887	891	880
1850	1170	1162	1120	1154	1160	1148	1148	1140
1900	1617	1671	1625	1653	1653	1620	1611	1600
1920	1811	2007	1970	1988	1983	1933	1917	1900
1930	2020	2223	2196	2208	2199	2138	2116	2105
1940	2295	2481	2474	2476	2462	2388	2361	2360
1950	2556	2790	2817	2809	2789	2700	2667	2670
1955	2780	2967	3019	3005	2983	2886	2851	2860
1960	3039	3159	3245	3226	3201	3096	3060	3080
1965	3345	3370	3497	3475	3448	3337	3300	3333
1970	3707	3597	3778	3755	3727	3613	3579	3640
1975	4086	3842	4089	4070	4043	3931	3904	4000
1980	4454	4103	4430	4423	4401	4299	4289	4400
1985	4851	4379	4801	4816	4804	4727	4747	5000
1990	5277	4665	5198	5250	5255	5225	5299	5720
1995	5682	4960	5613	5720	5753	5803	5969	6680
2000	6073	5257	6038	6221	6294	6466	6787	8000
2005	6453	5552	6463	6742	6867	7216	7783	10000
2010	6832	5841	6878	7269	7458	8042	8980	13333
2015	7207	6119	7275	7786	8048	8920	10376	20000
2020	7562	6383	7646	8282	8621	9813	11921	40000
2025	7896	6632	7987	8746	9162	10683	13515	¥
2050	9298	7617	9259	10483	11188	13918	19296	—
2075	10841	8249	9999	11459	12298	15503	21600	—
2100	11186	8661	10451	12031	12932	16323	22645	—
T® ¥	—	10282	12076	13913	14923	18564	25133	—

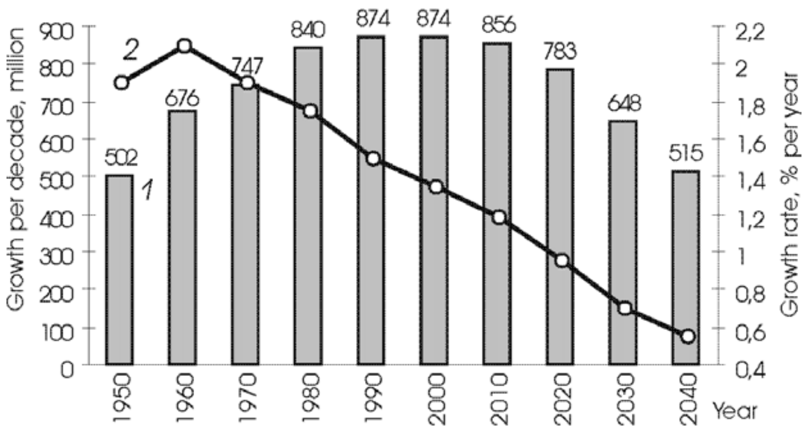


Figure A2. The demographic transition. UN data for 1995 [116]
1 — growth, averaged over a decade, (left scale). 2 — relative growth rate in % per year, (right scale)

A.4 Dimensionless Variables of Time and Population

Most calculations are seen best if they are presented in a dimensionless form, with the following variables for time and population:

$$t = \frac{T - T_1}{\tau} \quad \text{and} \quad n = \frac{N}{K} \tag{A12}$$

where time is measured in units of τ and N — in units of K. The constant $K = 62{,}000$ is the main numerical parameter of the global population system that enters into all equations and results in the dynamic theory. All the asymptotics that determine the scaling of temporal structures and the population are effective because this parameter is large. In fact, even its natural logarithm ln K= 11.03 is large. Similar to τ, K has two dimensions, numerically equal: one has a dimension relating to scaling populations, and the other is a dimensionless number. With the new variables the differential equations of growth and their solutions are:

$$\frac{dn}{dt} = \frac{n^2+1}{K}, \quad n = -\cot\frac{t}{K} \tag{A13a}$$

$$\frac{dn}{dt} = n^2, \quad nt = -K \tag{A13b}$$

$$\frac{dn}{dt} = \frac{K}{t^2+1}, \quad n = -K\cot^{-1}t \quad \text{or} \tag{A13c}$$

$$\frac{dt}{dn} = \frac{t^2+1}{K}, \quad t = -\cot\frac{n}{K} \tag{A13d}$$

The equations become compact and the conjugate symmetry of time and population is seen. How the singularities of hyperbolic growth are dealt with, if equations (A13a) and (A13d) are compared, is also apparent. In fact, near the singularity of the demographic transition at $t = 0$, the population becomes, in a sense, the independent variable. While physical time is invariant, time here appears as a systemic variable that is reciprocally connected with n as its complimentary variable. In other words, the moment of the demographic transition is determined by population growth and is not explicitly causally dependent on time.

The growth of population and the appearance of the singularity may be illustrated by a simple geometric construction of the tangent function. The time of development from T_0 to T_1 is represented by the angle j going counterclockwise in units of t, so that Kt = p/2. The radius OA is K units long sets the scale for population N, which is plotted on the tangent AC. Then the connection between population and time becomes:

$$\tan \mathrm{j} = \frac{AB}{OA} = \frac{N}{K} = n \tag{A14}$$

The beginning of Epoch **A** corresponds to a time change Dj=t and an increment of population DN = 1. Linear growth will be pursued up to j_B = Kt=1 and $N_B = K \tan 1$ at point B on the tangent AC. All further quadratic growth will be determined by hyperbolic growth of the population as j asymptotically approaches p/2.

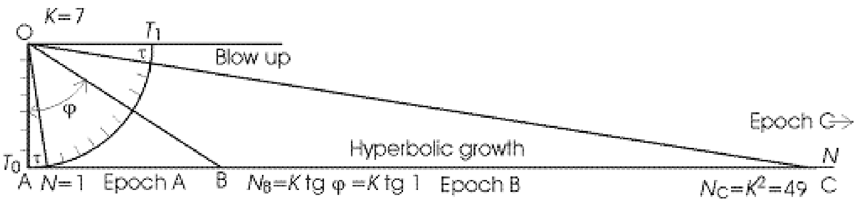


Figure A3. Tangent construction, showing the asymptotic limits in growth for K=7

The population will rapidly grow as $N = K$ (p/2 – j $^{-1}$ up to the last interval of time t This is the time of the blow-up, when the population will reach $N_c = K^2$. When time approaches T_1 and is closer than t, the demographic transition sets in and from equation (A13a) one has to pass to (A13d). In this case, the same construction may be used by substituting n into t, so as to describe growth from N ® N_∞ and T ® ∞. This is left to the reader. Fig. A3 also shows that for all the rest of development after Epoch **A**, the time left is twice as short. The construction demonstrates the origin of the asymptotics, and is drawn for K = 7, when time from T_0 to T_1 is divided into 11 intervals, as p/2 » 11/7 and $T_C = K^2 = 49$. Even in this case, asymptotics work well, as ln K = ln 7 = 1.95 provides an estimate of the number of demographic cycles: the 0th cycle lasts 7 units of time, the first cycle — 3, and the last cycle — one unit of time.

Growth rate during Epoch **B** is described by the quadratic growth rate:

$$\frac{dN}{dt} = \frac{N^2}{K^2} \qquad \text{(A15)}$$

which helps to understand the origin of growth and the meaning of K. The remarkable point is that this simple non-linear equation for the collective interaction describes growth covering five orders of magnitude with no other terms in the expression for the effective interaction or evolution in constants K and t

As a perturbation, linear growth appears only at the initial stage of anthropogenesis and at the demographic transition. From (A15), the limits for scaling can be immediately established by assuming that when $\Delta T = \tau$ or $\Delta t = 1$:

$$\frac{\Delta N}{\Delta t} = 1, \quad N_{A,B} \approx K; \quad \frac{\Delta N}{\Delta t} = K, \quad N_{1/2} = K\sqrt{K};$$
$$\frac{\Delta N}{\Delta t} = N, \quad N_{B,C} \approx K^2 \qquad \text{(A16)}$$

where the global population N_{AB} is estimated for the time of transition to Epoch **B**, the Neolithic at $N_{1/2}$ and N_1 indicating numbers for the limits of self-similar asymptotic growth.

A.5. Population Limit and the Number of People Who Ever Lived

The equation describing growth (A7) determine the global population limit to be asymptotically reached in the future:

$$N_{\infty} = \pi K^2 = 12 \text{ billion} \qquad \text{(A17)}$$

and the age of the population system at $t_0 = -K\pi/2$ is :

$$T_0 = T_1 - \frac{\pi}{2} K\tau = T_1 - \frac{\pi}{2}\sqrt{C\tau} = -4.4 \text{ million years ago} \qquad \text{(A18)}$$

The age of humankind can also be expressed by the global population at the high point of the population transition N_1 and τ. See also (3.3).

If growth is integrated from T_0 to T_1 the number of people who have ever lived is:

$$P_{0,1} = K \int_{t_0}^{t_{1/2}} \cot\frac{t}{K}\, dt + K \int_{t_{1/2}}^{0} K \cot^{-1} dt =$$
$$= \frac{1}{2} K^2 \ln K + \frac{1}{2} K^2 \ln(+ K) \cong K^2 \ln K \qquad \text{(A19)}$$

showing that by the Neolithic half of all humans have lived.

The same result may be obtained by rearranging the terms in (A15) and integrating:

$$P_{0,1} = \int_{t_0}^{t_1} N dt = K^2 \int_{K}^{K^2} d \ln N = K^2 \ln K \qquad \text{(A20)}$$

For the model $P_{0,1} = 2.25K^2 \ln K = 96 \approx 100$ billion people. This estimate of $P_{0,1}$ is in good agreement with estimates made by Keyfitz [53] and Weiss [22], who obtained numbers for P from 80 to 150 billion by approximating the growth of human numbers by a sequence of exponents. The multiplier $2.25 = 45:20$ appears because in integrating the effective length of life is assumed to be $t = 45$ years, although the quoted numbers were obtained for an effective lifespan of 20 years.

In the initial Epoch **A** of anthropogenesis the number of early hominids was approximately:

$$P_A = 2.25K \int_0^K \tan\frac{t'}{K}\, dt' = 2.25K^2 \ln\cos 1 \cong 5 \text{ billion.} \qquad \text{(A21)}$$

The larger number by Weiss is the result of assuming that the effective population during Epoch **A** was 50 billion. These estimates do not depend much on the model used, and are of general interest for anthropology and human population genetics.

A.6. Asymptotic Solutions and Autonomous Equations

The asymptotic merging of growth when (A13a) crosses (A13c) at the beginning of the Neolithic, half way on a logarithmic time scale is best seen if the expansions for the appropriate functions for growth from T_0 and T_1 are equated:

$$n = -\frac{K}{t}\left(1 - \frac{1}{3t^2} + \frac{1}{5t^4} - \dots\right), \qquad t^2 \geq 1 \qquad \text{(A22)}$$

$$n = -\frac{K}{t}\left(1 - \frac{t^2}{3K^2} - \frac{t^4}{45K^4} - \dots\right), \quad t^2 \leq \pi K^2. \qquad \text{(A23)}$$

These functions intersect at point A, half way on a logarithmic scale between T_0 and T_1:

$$t_{1/2} = -\sqrt{K} \quad \text{and} \quad N_{1/2} = K\sqrt{K} \qquad \text{(A24)}$$

at an angle $2/3K$ practically smooth for any large K. It is obvious that time may be reckoned from T_0, so as to have a solution beginning in

Epoch **A** at t_0. By excluding t from (A14c), an autonomous differential equation describing growth all through human history can be obtained. An autonomous equation does not explicitly contain time and the growth rate only depends on the state of the system — on n:

$$\frac{dn}{dt} = K \sin^2 \frac{n}{K} + \frac{1}{K} \tag{A25}$$

This equation is valid throughout all time and its solution describes the total human story:

$$n = K \tan^{-1}\left(\frac{1}{\sqrt{K^2+1}} \tan \frac{\sqrt{K^2+1}}{K^2} t'\right) \tag{A26}$$

For a large $K \gg 1$, this solution may be simplified and then it becomes symmetric:

$$\tan \frac{n}{K} = \frac{1}{K} \tan \frac{t'}{K} \tag{A27}$$

where time t' is reckoned from $t'_0 = 0$. This is the solution of the autonomous differential equation:

$$\frac{dn}{dt} = \frac{K^2 - 1}{K} \sin^2\left(\frac{n}{K}\right) + \frac{1}{K} \tag{A28}$$

which practically coincides with (A25) and $n_0 = 0$ as the initial condition at $t_0 = 0$. These expressions give a complete description of the human story right from its early origins and into the foreseeable future with no evolution of the constants.

The transition is best described by the cut-off function introduced in (A6), which corresponds to the observed data. In the case of an abrupt transition, when after the transition $N' \neq 0$, an oscillatory pattern, which has been obtained in mathematical models described by Cohen, develops [122].

It is of interest to compare logistic growth with global population growth. The logistic is described by the differential equation:

$$\frac{dn}{dt} = n(1 - n) \tag{A29}$$

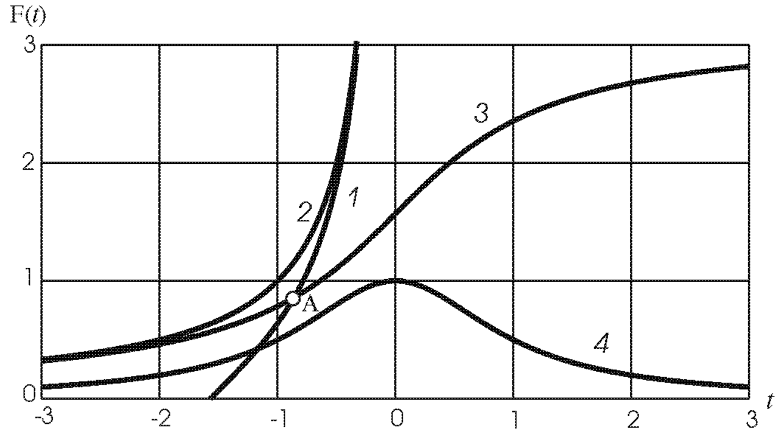


Figure A4. Functions F(t), appearing in the description of growth for K = 1

$$(1) - \cot t,\ (2) - \frac{-1}{t},\ (3) - \cot^{-1} t,\ (4) - \frac{1}{t^2+1}$$

Functions (1) and (3) intersect at A

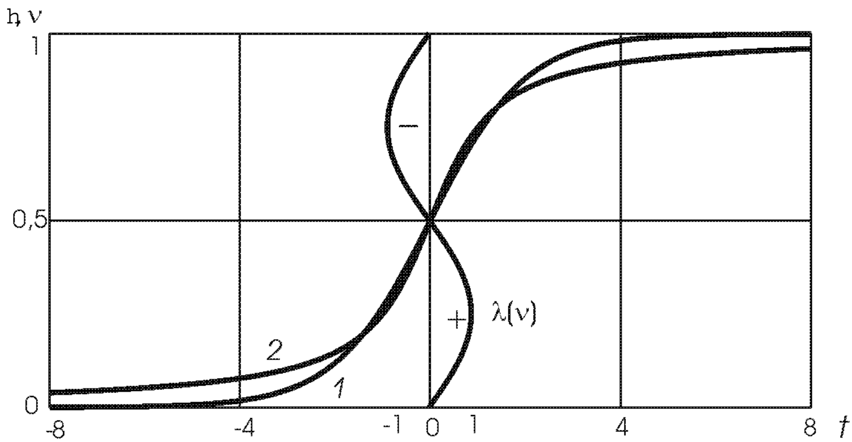


Figure A5. Comparing the logistic equation — (1) with the demographic transition model — (2). The Lyapunov index λ(ν) is shown for the demographic transition model (A31).

and its solution:

$$\mathrm{n} = \frac{1}{1 + e^{-t}} \qquad \text{(A30)}$$

where n is the normalised population that increases from 0 to 1 and can be compared with the demographic transition $\mathrm{h} = (1/\mathrm{p})\cot^{-1} t$. These functions are anti-symmetric at the point (0, 1/2) and practically coincide during the transition, but their asymptotes, both in the past and the future, are quite different. The logistic approaches zero as an exponent and for $\cot^{-1} t$ » $-t^{-1}$ the asymptote in the past and after the transition is hyperbolic.

A.7. Dynamic Stability of Growth

The dynamic stability of growth is determined by the growth of fluctuations. In a linear approximation, any disturbance $\mathrm{d}n = \mathrm{d}n_0 exp(\mathrm{l}t)$ grows or is damped depending on the sign of l Thus the Lyapunov index lis determined by:

$$\mathrm{l} = \frac{\P}{\P n}\left(\frac{dn}{dt}\right) = \sin 2\frac{n}{K} \qquad \text{(A31)}$$

According to this criterion growth from T_0 to T_1 is unstable as l³0 and for $n = (\mathrm{p}/4)K$, that occurs at $t = -1$, or in 1955 when the Lyapunov index reaches its maximum value $\mathrm{l}_{max} = 1$. Only after $T_1 = 2000$, as lchanges sign, does the growth stabilize and later remains asymptotically stable (see Fig. A5). In much the same way the logistic is also unstable up to the transition point, for in this case $\mathrm{l} = 1 - 2\mathrm{n}$.

The Lyapunov index deals with the linear stability of the 'short' equations for growth, where all internal processes are not taken into account. However, these processes can stabilize or destabilize the system. Stabilization, which is intuitively plausible, can be expected from migration. In fact, as described in Chapter 8, during the rising phase of the transition when the instability was the greatest in Europe there were massive migrations to the New World, which certainly stabilized the global demographic system. The greatest disturbance during the 20th century — World War I and World War II — was close to the phase of maximum growth and the instability of growth to be expected in the developed countries. These instabilities were systemic and caused by the internal degrees of freedom and lead to a loss of global stability and an 8–10% decrease in the population. This is a non-linear effect and happened because systemic development in many degrees of it freedom was upset. These considerations indicate that hyperbolic growth is the path of maximum development and once this track is left things can only get worse. In complex systems, this is a general principle because the system is evolving along an inherently stable path of maximum growth and most, if not all, changes will nearly always make the system less effective.

Haken studied the stability of systems when he was developing the principles of asymptotic methods and synergetics. The main motion is identified as $u(t)$, an **u**nstable slow motion, in our case $N(T)$, and the fast **s**table $s(t)$ motion in internal degrees of freedom, which by non-linear coupling stabilizes the main motion. In mechanics, the stabilizing effect of internal motion is seen when a spinning top is stabilized by gyroscopic forces or when rapid oscillations of a pendulum's suspension point brings in a stabilizing force. Strong focussing in accelerators is another example of stabilizing by a periodic field an inherently unstable orbital motion of charged particles. In the case of population growth, a more fundamental understanding can be expected when the internal degrees of freedom are taken into account in developing the theory of systemic growth.

The spatial distribution of the population should be taken into account when the stability of the world population system is determined. If diffusion is introduced into the equation of growth, a damping of systemic instabilities is to be expected because the Eigen-values of the Laplacian $\nabla^2 N$ are negative. This will require a more detailed analysis of fluctuations and instabilities of the solutions of partial differential equations, describing changes in space and time in population growth [13].

A.8. Structure of Time and Demographic Cycles

A significant property of the model is the change in the scaling of time, discussed in Chapter 5. The transformation of time can be expressed mathematically by the instantaneous exponential time of growth $T_e(T)$ as a function of time. In exponential growth T_e is a constant, but in hyperbolic growth it changes in time:

$$T_e = \left(\frac{1}{N}\frac{dN}{dT}\right)^{-1} = \frac{1}{\tau}[(T_1 - T)^2 + \tau^2]\cot^{-1}\frac{T_1 - T}{\tau} \qquad \text{(A32)}$$

or for the past, before T_1:

$$T_e(T) \approx T_1 - T \qquad \text{(A33)}$$

The exponential time of growth is obviously connected with the Lyapunov index $T_e = 2\tau/\lambda$ In other words, instabilities grow twice as fast as the population and that is why the damping is essential. After $T_1\ \lambda \leq 0$ the stability of growth rapidly rises, reaching its maximum at $T_1 + \tau$ in 2045, and then gradually decreases, nevertheless always retaining asymptotic stability. The exponential time of growth after the transition case increases as

$$T_e = (T - T_1)^2/\tau \qquad \text{(A34)}$$

The periodicity of the demographic cycles appears as a sequence of intervals:

$$\Delta T(\theta) = K\tau \exp(-\theta) \qquad \text{(A35)}$$

where θ is the number of the period and the integer part of $\ln t' = \ln|t - t_1|$ beginning at $\theta = 0$ and ending at $\theta = \ln K = 11$.

The 0th period lasts $\Delta T = K\tau = 2.8$ Million years and the last is τ Then for the whole of the past, before T_1:

$$T_1 - T_0 = K\tau \sum_0^{\ln K} \exp(-\theta) = K\tau\,[1 + \exp(-1) + \exp(-2) + \ldots + \exp(-\ln K) \approx \frac{e}{e-1}K\tau = 1.582K\tau \approx \frac{\pi}{2}K\tau = 1.571K\tau \qquad \text{(A36)}$$

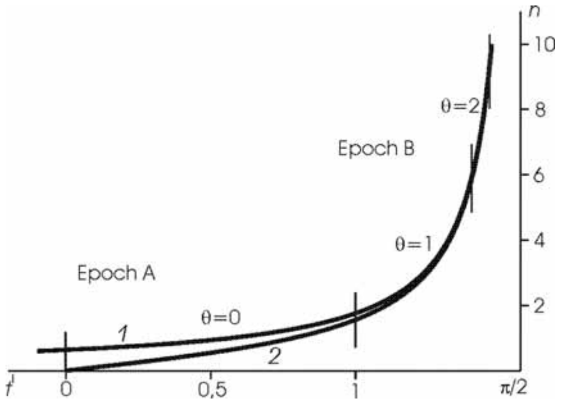


Figure A6. Comparing the initial stages of hyperbolic (1) and growth as $n = \tan t¢/K$ (2) (See Fig. 4.2)

In each of the ln $K = 11$ cycles of Epoch **B,** when the exponentially spaced cycles change from 1 million years to 45 years, $\mathrm{D}P = 2.25\ K^2 = 9$ billion people lived. The slight difference in the total length of human development in (A21) and (A36) occurs because growth is hyperbolic in the first equation and in the second case $n = \tan t'/K$. From the end of each cycle the time to the singularity

$$\frac{\Delta T}{e-1} = 0.58\Delta T \qquad \text{(A37)}$$

is approximately equal to half of the cycle's duration (A35). These periods can also be derived by generalising the equation of growth to the complex variables — the Ginzburg-Landau equation — in the theory of phase transitions [154].

In the short autonomous equation (A6a), N is the result of averaging the population over time. In the case of global population growth, this time is of the order of T_{BP}, the age of the point where growth is to be determined. This means that the 'short' equation is actually non-local and implies an inherent and time dependent memory: In the Lower Paleolithic the time of averaging is a million years and in the Middle Ages — a thousand years and at present is limited by t In effect, the postulated global interaction is both non-linear and non-local, in time and space, as space is that of finite Earth.

A.9. Scaling Urban Population and Fluctuations

It has been noted that in a country, the ranking of towns according to population can be described by a hyperbolic distribution and hence they scale [57] (Fig. 9.4). Large towns usually do not scale, and this is attributed to the singular nature of these towns. Given their sheer size, they cannot belong to a statistically valid fractal set. But this may be expected for a global ranking of towns. In this case such a set does exist and it is the global population. Then for the population of a town of rank *R* the following expression is suggested:

$$U(R) = \frac{U_0 \ln U_0}{R + \ln U_0} \tag{A38}$$

that for $R \geq \ln U_0$ becomes a fractal hyperbolic distribution and as $R \geq 0$ describes the population of the largest towns in the world. Integrating this distribution from $R = 0$ to $R_{max} = U_0 \ln U_0$ and when $U_{min} = 1$, the population of the world becomes:

$$N = \int_{R_{min}}^{R_{max}} \frac{U_0 \ln U_0}{R + \ln U_0} dR = U_0 \ln^2 U_0 \tag{A39}$$

By solving for U_0, one can find the population of the largest town in the world and rank all towns and villages. This distribution is based on the conjecture that $\ln U_0$ provides the natural scaling unit, so as to get rid of the singularity of the hyperbolic distribution at rank zero. It is obvious that this distribution is not applicable to any individual country. (A38) provides a satisfactory description of global ranking and supports the idea of treating the global population as a single interacting system, where such a statistical approach is valid.

To describe the demographic transition, Chesnais introduced the demographic multiplier *M*, which is defined in the model (Table 7.1):

$$M = \frac{N(T_1+\tau)}{N(T_1-\tau)} = \frac{\cot^{-1}(-1)}{\cot^{-1}1} = 3.00 \tag{A40}$$

where $T_1-\tau$ and $T_1+\tau$ are the beginning and the end moments of the transition. In the model, the population of the world at the points, $T_1-\tau$, $T_1+\tau$ and T_∞ are in the ratios: 1:2:3:4. During the main part of the demographic transition from $T_1-\tau$ to $T_1+\tau$, the population grows linearly, if third order corrections are not taken into account (Table 1.2). Linear growth in the vicinity of the critical date T_1 is similar to linear growth assumed in Epoch **A**. Although it is not the slow growth of numbers of *Homo* in that distant epoch, but rather the gradual biological evolution and accumulation of a pool of genes that led to the appearance of *Homo habilis.*

In the initial equation (A1), by passing to the short equations of growth, the spatial terms have been asymptotically excluded. This is possible because of the finite size of the Earth and of the global population. In other words, we are dealing with a finite system and do not have to go to the limit of the continuum, as is done in the theory of gases. This assumption leads to the synchronous pattern of global development as well as justifies, in the first approximation, the exclusion of spatial terms in the short equation of growth, although these terms do contribute to the stability of growth.

A crude estimate of the fluctuations that can be expected in the population of the world was made in [7]. The main point is that fluctuations are experienced not by *N*, but by *n*. In other words, one has to take into account the coherence and structures with a characteristic size of the order of *K*. Then fluctuations are:

$$\delta n \approx \sqrt{n} \tag{A41}$$

and $\delta N = K\sqrt{N/K} = \sqrt{KN} \approx 20$ million for the present. On a relative scale, the fluctuations will reach a maximum of the order of *K* at the beginning of Epoch **B**. This corresponds to anthropological data on growth in the Lower Paleolithic. These assumptions will have to be modified during the initial stages of anthropogenesis, as the coherent population structures had yet to organise themselves at that time. On the other hand, these extreme conditions are well beyond the scope of the model.

Apart from random fluctuations in the global population system, population waves, generated by a large coherent instability, propagate through the system. These waves are known as the demographic echo. The most prominent is the echo and the subsequent baby boom after World War II (Figs. 2.5 and 7.2). It could be conjectured that the present rapid decline in the TFR in developed countries is of the same nature as a collective reaction to a critical situation.

This discussion brought out the main features of the population system's growth, which that can reveal, in surprising detail, the human story in quantitative terms, when previously, only a descriptive, chronological treatment was possible. The model, or theory for that matter, describes the whole development of mankind by a single effective parameter K which within the premises of the model does not change. That means that no evolution in the quadratic interaction is noticeable. The fact that the same law of growth is valid as the global population grows by five orders of magnitude is unusual because, in theories of phase transitions, the quadratic term is often considered to be the first term in an expansion of the interaction. The validity of quadratic growth could be explained if growth is represented in logarithmic space, then the limits of change are much less and are determined by $\ln K = 11$.

The phenomenological theory of demographic growth is now open to further studies in complexity, as a well defined problem in the explosive evolution of non-linear systems far from equilibrium. The development of an advanced statistical, rather than phenomenological, theory of the global population system could be the next step in working out the theory of growth of mankind.

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The General Theory of the Growth of Mankind

Synergetics and Studies of the Future
(with S. Kurdyumov and G. Malinetzkii)

"Many measures to halt the growth of population are welcome and regionally helpful. They are integrated in the Global Marshall Plan Initiative and therefore part of a necessary global effort; thanks to Kapitza, Radermacher, Riegler and many others committed. They give us hope for a possible positive change of the future of our children and grandchildren."

Hans Martin Scheuch
Rotarian Action Group for Population and Development
Chairman of the Intercountry Committee Nepal-Germany

"After growing slowly for most of human history, the world's population more than doubled in the last century and reached 6,5 billion last year (2005). More people than ever are added to the world population each year and record numbers of young people mean that the world's population will increase for decades to come.

At the same time, the actual rate of growth has slowed and the trend towards smaller families continues. The continued slowing of population growth, however, depends on choices and actions in the next years - by researchers, individuals, governments and non-governmental organizations.

In this respect we welcome Sergey Kapitza's publication "Global Population Blow-Up and After" and the commitment of the Club of Rome and the Global Marshall Plan Initiative to support demographic research and to document the impact of demography on any development which aims to be sustainable."

Dr. Joerg Maas
German Foundation for Global Population

Global Marshall Plan Initiative

The book "Global Population Blow Up and after" is dedicated to all organizations that have been concerned with world population development since years. It should be mentioned respectavely: Allan Guttmacher Institute, German Foundation for World Population, Lions Club, Population Institute, Population Reference Bureau – Washington DC, Rotarian Action Group on Population and Development, 34 Million Friends of UNFPA, United Nations Population Fund (UNFPA), World Demographic Association, World Population Foundation, World Watch, United Nations Population Devision.

What is the Global Marshall Plan?

The five key aims are:

1. Rapid implementation of the globally agreed upon UN Millennium Development goals;
2.Raising of an average of additional 100 billion US-Dollar per year for development cooperation during the period of 2008-2015;
3. Charging global transactions to raise these necessary financial resources;
4. Gradual realization of a worldwide Eco-Social Market Economy and overcoming of the market fundamentalism by the establishment of a better regulatory framework for the world economy;
5. A fair global partnership. New forms of the appropriation of funds, directed to the grassroots level, transparent and fighting corruption.

Why do we need a Global Marshall Plan?

The state of global affairs is scandalous. Deregulated globalization produces growing poverty, questions of allocation between North and South, migration, cultural conflicts, terror, war, and environmental catastrophes. Today's conditions of globalization cause strong negative consequences for the majority of humankind – in the South and in the North. Therefore we need a better and binding global regulatory framework for the world's economy, which harmonizes economic processes with environment, society and cultural diversity. A shared learning process of the North and the South – which meets in a fair global contract – is a promising way into the future.

Ethical Values for Global Balance

The religions of the world and the intercultural philosophical movement share ethic and moral basic principles, how they are stipulated in the "Declaration toward a Global Ethic" and the "Earth Charter" amongst others. The principles of justice and the Golden Rule of reciprocity are central: "Do unto others as you would have others do unto you." Relating to the people living today, this leads to a responsibility for the dignity of every human being and for the chance to unfold all human potential. With regard to future generations we are responsible for the conservation of our natural environment. From the Golden Rule derives the necessity of an ecological and social oriented behavior.

1. Achieve the UN Millennium Goals until 2015

The realization of the UN Millennium Development Goals, ratified in 2000 and signed by 191 nation states, is an important intermediate step for a more just world and a sustainable development. The following goals should be achieved until 2015:

The Millennium Development Goals

1 Eradicate extreme poverty and hunger;
2 Achieve universal primary education;
3 Promote gender equality and empower women;
4 Reduce child mortality;
5 Improve maternal health;
6 Combat HIV/AIDS, malaria, and other diseases;
7 Ensure environmental sustainability;
8 Develop a global partnership for development;

2. Raising of an additional 100 billion US-$ a year

Compared to 2004, 100 billion US-Dollar additional funds are necessary on average from 2008 until 2015 to implement the UN Millennium Development Goals, and to finance directly related concerns in favor of the global common welfare. In comparison: 100 billion US-Dollar are less than 0.3 per cent of the world's gross national product and merely 0.02 per cent of the annual global capital flows.

3. Fair mechanisms to raise the necessary funds

The raising of national budgets towards 0.7 of the gross national product, the establishment of a north-south-cooperation in partnership in the agricultural sector, as well as reasonable methods of debt relief for the least developed countries are important. Additionally, new financing sources should be used that target global value-added processes and the usage of global common goods. Examples are a levy on international financial transactions (Tobin tax), a Terra-tax on cross-border world trade, trade with equal per capita emission rights, a kerosene tax, or special drawing rights with the International Monetary Fund.

4. A worldwide Eco-Social Market Economy

With the gradual realization of a worldwide Eco-Social Market Economy a better regulatory framework for the world's economy should be established and the global market fundamentalism should be overcome. In line with a fair global contract, reforms, and the interlinking of existing global regimes and institutions for economy, environment, social welfare, and culture are needed (e.g., in the regulation fields of the UN and its special sessions the ILO, the UNDP, the UNEP, and the UNESCO as well as the WTO, the IWF, and the World Bank).

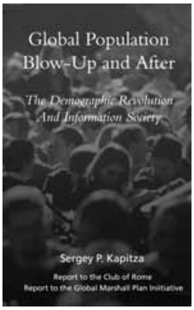
5. Fair partnership and grassroots oriented appropriation of funds

The prerequisites for the attainment of a reasonable regulatory framework are a fair cooperation in partnership on all levels and an adequate flow of financial resources. The advancement of Good Governance, Education, the fight against corruption as well as coordinated and grassroots oriented forms of appropriation of funds are considered decisive for self-directed development. Micro-financing and the cooperation with native development partners are concrete examples.

Extract of Supporting Organizations of the Global Marshall Plan

Aachen Foundation Kathy Beys – AIESEC Germany and Austria – AK Gerechtigkeit der Evangelischen Akademikerschaft e.V. (EaiD) – Akademie für Natur und Umwelt des Landes Schleswig-Holstein – Alpen-Adria-University Klagenfurt – American Council for the United Nations University – Church Development Services – Bank für Sozialwirtschaft – Bauverein zu Hamburg – Beratungsring – Biopolitics International Organization – Breinlinger + Partner – Bundesland Burgenland, Austria – Bundesland Oberösterreich, Austria – Bundesland Salzburg, Austria – Bundesland Steiermark, Austria – Bundesland Voralberg – Bund Naturschutz Schwabach – Cap Anamur – Club of Budapest – Club of Rome – COMMARO mobile trading systems GmbH – Committee for a Democratic UN – Community Mallnitz – Delphic Council Germany (DRD) – Deutsche Aktionsgemeinschaft Bildung, Erfindung, Innovation e.V. (DABEI) – Deutsche Bundesstiftung Umwelt (DBU) – Deutscher Erfinderverband e.V. (DEV) – Gemeinschaft NRW Die Lichtbrücke e.V. – Doehler GmbH, Donau-University Krems – Eco-Social Fora Croatia, Austria and Hungary – Eco-Social Forum Europe – EPEA Internationale Umweltforschung GmbH – Fairness Foundation – Farbfieber – Federal State Upper Austria – Federal Association for Business Promotion and Foreign Trade – Femme Total e.V. – Foundation Apfelbaum – Foundation Kinder in Afrika – Foundation KIT Initiative Deutschland – Fundación Agreste, Argentina – German Association for Water, Wastewater and Waste (DWA) – German Foundation for World Population (DSW) – Giraffentoast, Global Contract Foundation, Hamburg – Green Budget Germany (FÖS) – Green Helmets – Handelskontor Willmann – Hauptkirche St. Katharinen, Hamburg – Indienhilfe e.V. – Institute for Environment

– Peace and Development, Vienna – Interdisziplinäre Gesellschaft e.V. (ISG) – International Students Club e.V. – Junior Chamber Germany (WJD) – Junior Chamber International (JCI) – Katholische Kirchenstiftung Verklärung Christi – Katholischer Laienrat Austria – KEMEL (Center of Greek Volunteer Top-Managers) – Krämer Marktforschung GmbH – Leagas Delaney Hamburg – Lebenschancen International e.V. – Marie-Schlei-Verein – MCC Public Relation – memo AG – Meusel & Begeer GbR, Positive Concept – Mouvement Ecologique a.s.b.l., Luxembourg Section of Friends of the Earth – Netz innovativer Bürgerinnen und Bürger (NiBB) – Netzwerk-Zeitgeist NRW – Norddeutsche Stiftung Umwelt und Entwicklung – Nova Europa – Christlich-soziale Plattform für ein föderatives Europa – Ökologisch-Demokratische-Partei (ödp) – OpenSpace-Online GmbH – Peter-Hesse-Foundation – Protestant Academy Tutzing – Reformierter Bund – Research Institute for Applied Knowlegde Processing (FAW/n) – Robert Jungk Bibliothek für Zukunftsfragen, Austria – Rotary Club Nürnberger Land Hersbruck – Rotary Club Obersdorf – Rotary Club Oberstaufen-Immenstadt – SBP GmbH (Schlaich Bergermann und Partner) – Schweizerische Vereinigung für ökologisch bewusste Unternehmensführung – Society of Intercultural Philosophy – SpardaBank Munich e.V. – Swiss Solar Energy – Society SSES – tegut – Terra One World Network e.V. – The United World Philharmonic Youth Orchestra – The Western German Chamber of Crafts and Skilled Trades' Council – Umweltdachverband, University für Bodenkultur, Vienna – University.Club Klagenfurt – United for Africa – VENRO (Association of German development non-governmental organisations) – Verband Druck und Medien Nord e.V. – Volksbank Goch-Kevelär eG – Volksbank Neu-Ulm eG – World Parliament on Culture – Westdeutscher Handwerkskammertag – World in Union e. V. – YOIS, Youth for Intergenerational Justice and Sustainability – Zukunftsstiftung Entwicklungshilfe der Gemeinnützigen Treuhandstelle e.V. – and many more



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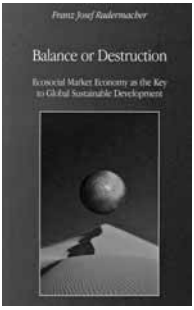

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