Global Population Blow – up and After.
The Demographic Imperative in a Changing World

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ABSTRACT

Of all the global problems looming on our common horizon that of population growth comes first. It sets the scene for considering major issues of social and economic development, of culture, science and education, of growth and security. In dealing with these matters a new way has to be found to comprehend the challenge of change. For one has to go beyond the agenda of demography and economics, sociology and anthropology, and see mankind as an evolving system. Without a broad vision of our past it is impossible to understand the predicament of mankind, the crisis now facing us in so many dimensions of life. Only then one can project our future development after the demographic revolution and stabilization of population, where education and science will become the main issues in a knowledge society of an information-dominated world.

1. Introduction

The world is facing changes never experienced before and to understand them we have to look at the global scene in space and time, right from our very origins. Only by thinking globally, can we assess the magnitude of the worldwide changes through which we are now passing. But from the beginning a straightforward question should be answered. What does this broad approach, with an extensive time scale, spanning a million years and encompassing all the people ever inhabiting our planet, really mean for each of us, our town or country, where we live. For do not the local circumstances provide all that matters for explaining the facts of life?

That is why for many these studies may seem to be out of place and irrelevant to what is happening here and now. The answer is that all large-scale events of history, everything that occurred in our past does matter for the life and wellbeing of every one of us today, as these consequences are often subtle and indirect, the profound messages of history being slow in coming, but full of meaning. They deal with connections between generations, values, and the very sense of our existence. The intellectual tradition of Russia shows the power of this approach in our thinking, and these signals are most in demand at a time of crisis.

We are dealing with an interdisciplinary problem in an attempt to describe the human experience, right from its very beginning. Recent research has shown that this can be done by working out a quantitative description of the growth of human numbers, based on a mathematical model. Probably the first to apply mathematical reasoning to social problems was Thomas Malthus. Malthus proposed the *population principle* – that resources set the limits to growth, and hunger limits the multiplication of people. His ideas have had singular influence on economists, political scientists and moral philosophers for the last two hundred years. Interest in his legacy has been aroused by the reports to the Club of Rome suggesting that the ‘limits to growth’ is due to limits in resources.

The following study refutes these Malthusian concepts and indicates that in an open evolving and self-organising system of the global population internal processes determine growth. Stated as the *population imperative*, this principle operates throughout the whole development of mankind. What determines global development is the growth and distribution of knowledge. That is why modern society is now loosely described as a knowledge society. To accept this, a new way for describing our development has to be worked out, taking into account the past, which is much closer than we think.

2. Modelling global population growth

Mathematical modelling, which to some may seem to be abstract and detached, even mechanistic and inhuman, has led to a quantitative description of our development by novel methods [1,2]. These methods, developed in physics provide a common approach to the non-linear dynamics of complex systems. Now these methods are used to develop the theory of global population growth, which was conspicuously absent in this field of research. Most of these concepts come from physics are of a modern, non-linear vintage, like collective interactions, self-organisation and chaos. The fundamental ideas of Ilia Prigogine [3] on the evolution and self-organisation of open systems and the methods of synergetics, developed by Herman Haken [4], were crucial for the whole effort of a non-linear study in complexity bringing in new metaphors, enlarging the scope of our thinking and vision in terms of 'soft' modelling, discussed by Arnold.

In this study mankind is treated as a system, not breaking it up into countries or regions, as it is subdivided in traditional studies of anthropology and demography, history or economics. By extending the temporal dimension into the past, back to the very origins of man, we shall consider the development of mankind right from its beginning. This proved to be a significant step, for only over a long span of time has it become possible to work out the laws determining the growth of human numbers. This also meant abandoning reductionist reasoning for historians – Karl Jaspers, Nicolai Konrad [5], Immanuel Wallerstein, Igor Diakonoff [6] – have all consistently stated that fundamentally history can only be understood globally. Fernand Braudel, who did much to establish this attitude, stated: 'there are no substantial truths concerning humans, except on a global level' [7], however exiting are the particulars of our past.

Concerning models Herbert Simon has noted that '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... Modelling, then calls for some basic principles to manage this complexity'. To get away with the 'curse of complexity', in the following model the global population becomes the dominant variable, as suggested by Haken in synergetics, expressing the principle of the demographic imperative in global population dynamics. Then the number of variables is reduced by averaging to a single one – the global population and the growth rate is seen to be proportional to the square of the total number of people on Earth expressing the network complexity of the system. On the other hand recent research on the early evolution of the human brain has shown that the capacity to grow appeared suddenly and is due to a single gene, which unleashed development well beyond all other comparable creatures like the chimpanzee [8]. Since then growth for more than a million years is dynamically self-similar and scales times pursuing a common pattern of development. This provides for a plausible estimate for the beginning of the human story 4 – 5 million years ago and describes our growth and development up to the blow-up of the demographic transition.

The model is based on a description of growth by a generalised co-operative phenomenological interaction. In the framework of the model it is the driving force leading to growth and the only resource, which is limiting growth and development. To this interaction we owe the remarkable accelerating hyperbolic blow-up of human numbers. For human beings have spread all over the globe and at present outnumber by five orders of magnitude – a 100 000 – all other animals of comparable size and position in the food chain. Only domestic animals, husbanded by man, are as numerous being attached to the human population.

The quadratic interaction sums all relevant factors by a statistical collective interaction when causality is expressed in probabilistic terms. It includes food and housing, industry and transportation, education and medicine, science and technology, communication and mass media, armies and police, religion and arts, etc. The interaction is due on an exchange of information, propagated and multiplied throughout humanity right since the appearance of *Homo habilis* – the tool-making man, when speech and language developed and fire was mastered. In this developing population system growth is not explicitly determined by the birth rate. Although the growth rate is equal to the difference between the birth and death rates, growth is determined by the social and economic conditions, the development of society.

The collective global interaction is due to an exchange of acquired information. This leads to social inheritance, similar to Lamarckian evolution, as opposed to biological, Darwinian evolution, where information is transmitted genetically. Cultural interaction, transmitted mainly by language between generations is a fundamental feature of society, a manifestation of the unique capacity of the human mind and consciousness. The interaction, since it suddenly appeared 5 to 7 million years ago, has not really evolved. The constants, determining its rate over the last million years are the same, and may be described within the data available by a single parameter.

On a semi-logarithmic plot growth up to the population explosion is hyperbolic and when it approaches year 2000, it goes off to infinity. Then an abrupt change in the pattern of growth takes place and the global population in the immediate future levels off at 10 – 12 billion. An essentially non-linear and rapid transformation the demographic transition involves many processes, interdependently coupled, and all happening at the same time. Only in terms of a systemic approach and by treating the whole phenomenon as a sequence of phase transitions of the type well known in physics, it is really possible to understand the complex nature of what is going on in terms of a collective global phenomenon.

In this study, when discussing the state of the world in an attempt to discern the trends of development, demographic factors are mainly taken into account. It should be emphasized that in this case the population of the world becomes the main characteristic of growth and measure of development. It is this parameter that we shall use throughout the discussion of the growth of mankind in developing a non-contradictory and consistent quantitative systemic theory to describe the gross features of the past and present. But only the concepts of anthropology and history, economics and sociology can add a further dimension to these numbers, provide a socially relevant content, where the human side of growth and development, of wealth and misery, enter the analysis. For in these terms we customarily seek to find an explanation of what is happening, expressing them as economic power and political will in ‘explaining’ our past and facing the present predicament. This can only be done, if an understanding is reached of the grand design of history, reconciling the local and temporal events, often irregular and chaotic, with the dictate of the demographic imperative. The global population as a system is both isolated and open meaning that it can draw on the resources of the out-

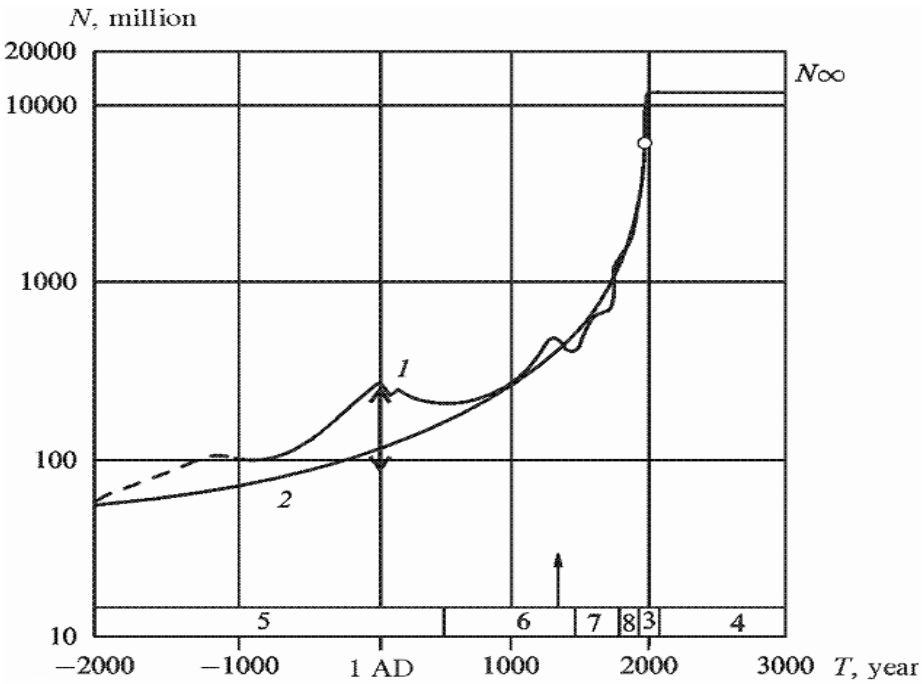

Figure 1. Population of the world from 2000 BC to 3000 AC. Limit $N_\infty = 10 - 12$ billions

1 – data for global population [9], 2 – blow-up growth [10], 3 – demographic transition, 4 – stabilized population, 5 – Ancient world, 6 – Middle Ages, 7 – Modernity, 8 – Recent history, ↑ – the Plague. ↕ – error, ∘ – 1995. On a semi-logarithmic plot exponential growth will appear as a straight line and at no time can describe the growth of the global population. As the demographic transition is approached, the time of history is compressed, with 9 billion people living through each of the 11 periods of the past.

side world, of the environment,. No constraints and limits appear in the theory, as far as external resources are concerned: in economic theory these are termed open-access resources. When the whole population of the world is treated as a system, a single entity, the details and events are all averaged and mixed in the totality of the system. In other words, the whole approach is essentially statistical and cannot be expected to take account of details, however significant they may seem. Nevertheless these partial events should be seen on the backdrop, the landscape of the total picture.

When depicting the overall process of development by an essentially non-linear model it should be kept in mind that it cannot be directly applied to local or regional growth, for we are dealing with a collective phenomenon. The global process of development definitely does influence all of its parts by the connections and interactions implied in the model and any part of the global system that is separated from the main body of mankind will inevitably lag in its growth and development. After the demographic revolution the global population is to stabilize as the world is moving into a new age structure, when the number of older people is to outnumber the younger ones. The most important changes are due to the development of an information-dominated society, where of central importance become culture, science and education. This should be of our main concern in assessing the future of the world, as it is entering the 21st century passing through its greatest crisis.

3. The open model and the population imperative

The results of modeling are all shown in the Table, summing up both the outcome of calculations and observations of historians, anthropologists and demographers, although global populations in these bygone epochs are known only within an order of magnitude

Growth and development of mankind, shown on a logarithmic scale

EPOCH	Period Phase	Date year	Number of people	Cultural period	ΔT years	Events in history, culture, and technology
C		2200	11×10^9	Stabilising world Population		Global population limit $10\text{-}12\times10^9$ Changing age distribution
		2050	9×10^9		125	Globalisation
	T_1	2000	6×10^9	Global demographic Revolution	45	Urbanisation, Internet
B	11	1955	3×10^9		45	Biotechnology Computers
	10	1840	1×10^9	Recent	125	World Wars Electric power
	9	1500		Modernity	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 civilisation, Axial time China, Confucius, India, Buddha,
	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 Language
	3	220 000	10^6	Acheulean	140 000	*Homo sapiens* Speech, Fire domesticated
	2	600 000		Chelles	380 000	Europe and Asia populated Hand axes
	1	1600 000	10^5	Olduvai	1000 000	Choppers *Homo habilis*
A	T_0	4 – 5 Ma	(1)	Anthropogene	3000 000	Hominida separate from Hominoids. Appearance of the HAR1 gene and brain growth (?)

The success of modeling global population growth and its general agreement with historic and anthropological data both in population numbers, and with the cycles depicting major epochs of global history observed in our past is impressive. Thus the informational interaction is essential from the beginning of the human story, for all other activities are really only life support systems, which ensure the existence and sustain the multiplication of humans.

The transfer and distribution of information from one generation to the next – knowledge and technology, customs and crafts, art and religion, and, finally, ideas and concepts of science – is peculiar to human beings and human society, and what makes us essentially different from all animals [11]. Consider the very first steps of a human being, which are quite different from those of an animal. In this process education and training in all forms and varieties, including games, is a major part of human development. It begins with a long childhood, first learning to speak and mastering language, being brought up, taught and educated in *the making of a man*, to use an old expression, as a member of society. This now takes 20 to 30 years and is essential for

every human being. Information is transmitted vertically between generations, establishing powerful links both with the past and contemporaries, links deeply entrenched in the personality of each member of society. Information is also transferred horizontally – in the space of informational interaction, synchronizing the grand periods of global development, as it happens throughout the ages. Thus globalization is seen both in the periods of prehistory and history, and strongly indicates, if not proves, the global nature of the interaction operating throughout our entire past.

An important outcome of the model is the compression of time of social development as the pattern of quadratic growth accelerates over the ages. This change in the scaling of time has been long recognized by historians and expressed by the concept of *longue durée*, as the change in the duration of processes in history. The transformation of the inner time of systemic development is discussed by Prigogine [12] and in the model it is explained in terms of the kinematics of self-similar hyperbolic growth. This interpretation of time in history in a way of its own follows the ideas of relativity of time in physics first explored by Einstein.

In exponential growth the scale of time does not change. But for hyperbolic growth at any moment in the past an instantaneous exponential time of growth may be worked out, which is equal to the time reckoned from the high point of the global demographic transition. As we approach the present, the population blows up at the global demographic transition, which is only 90 years long being limited by the effective human life span of 45 years. Thus the population explosion is cut off by the demographic transition. By an accident of history and of our calendar the maximum growth rate of the transition is in year 2000. After that in the constant population of our foreseeable future a new temporal structure is to develop.

4. The demographic revolution

Demography and the model indicate that mankind is now rapidly passing through a critical period of the population transition, when unlimited growth changes into limited growth. Discovered by Landry first for France this is a veritable revolution drastically changing our long established pattern of growth and development [13]. For more than a million years man was concerned with numerical growth. Growth on all counts: more children, more food, more space, more arms, more power in all dimensions of life. Now this paradigm of growth is changing, a change never experienced before.

It is well established that all countries pass through a maximum growth rate at the demographic transition then followed by stabilisation of the population. This has been observed for all developed countries and is now being seen in countries of the developing world. During the transition death and birth rates rapidly change, beginning with an initial decrease in the death rate. The consequent fall in the birth rate starts later, and is accompanied by economic development, an increase in the standard of life and the development of health services, initially leading to a longer life expectancy. Due to the interaction of these two factors, the growth rate passes through its maximum value. Later, as the result of the decrease both in birth and death rates, which tend to the same limit after the transition, the resulting growth rate gradually approaches zero, as the population is to stabilise. The stabilisation of the global population may be seen by some as the result of appropriate demographic policies. But these policies, conducted in tune with the natural trend of the demographic imperative, are but a part of the transformation, of the demographic revolution. For any country migration may modify this idealised description, but globally emigration only redistributes population and does not enter into the global growth rate, as far as the population is limited to our planet.

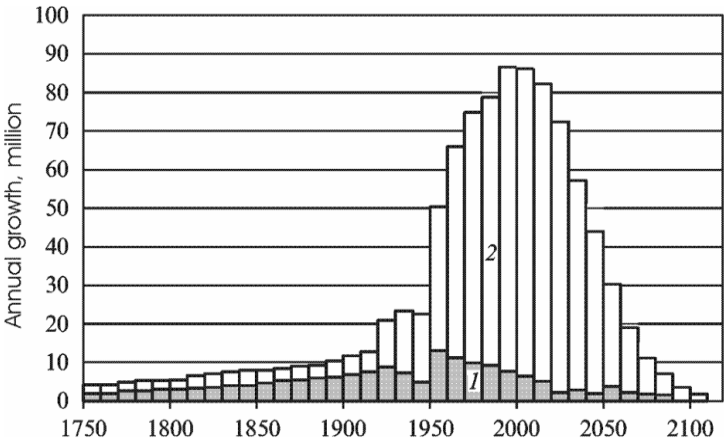

Figure 2. World demographic transition 1750 – 2100 (UN data)

Annual growth averaged over a decade: 1 – developed countries, 2 – developing countries. The global transition is remarkably short with a width of only 90 years, centred on year 2000.

This sequence of events shows that the whole change is rapid and at no point during the transition is the population in any state of relative equilibrium. In fact, we are dealing with a non-equilibrium transition, centred on year 2000, a veritable shock wave that could hardly happen faster. As a result of the demographic transition the population ceases to grow and a marked change in the age distribution of the population develops. This is the last in the sequence of events in the demographic revolution and a very significant transformation to happen globally in society.

The global population transition takes only 90 years, and during this time, that is 1/50000 of all our history, a fundamental change in the mode of the growth of humankind is to happen. To imagine how abrupt the transition really is, it makes sense to place the beginning of growth. On Fig. 2 the point corresponding to 5 million years ago is well off the limits of the page, somewhere around a kilometre to the left! All through that time human numbers grew in a self-similar pattern, following a stable and sustained path of hyperbolic growth now culminating at the demographic revolution.

This description makes it all the more to difficult to identify the factors determining the passage through the transition, although the educational and medical aspects are probably the most important social and demographic ones in the growth and economic development of each country. These processes are accompanied by urbanisation, with vast movements of rural population to towns. As the population of the world acts as a truly global community, undergoing a common transformation, the transition in the developed and developing countries are happening practically at the same time. They are separated by a mere 50 years, showing that in a fundamental way these countries are not so different as it is usually assumed. Although we are dealing with the compressed time of history, this is a significant point to be kept in mind.

A different image of the transition is seen, if we refer to the number of people – some 10 billion – who are to live through the demographic transition. This is $1/10^{th}$ of the hundred billion people who ever lived, and is the chance for a human being to be caught into this critical period of rapid change [14]. As the global demographic transition develops, a marked sharpening of the transition in developing countries takes place: the later the transition, the shorter its duration. The narrowing is due to the non-linear interaction between countries, constituting the global population system. It also takes place in the largest countries – China and India. Sub-global in population size and bringing together regions at very different stages of development, these countries demonstrate the same synchronizing interaction in the collective way they experience

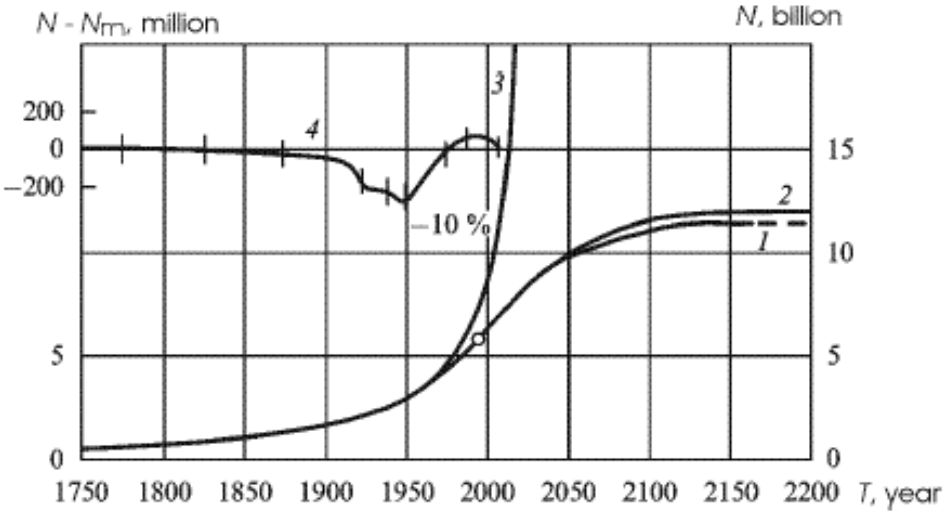

Figure 3. Population of the world from 1750 to 2150

1 – projections by IIASA and UN, 2 – Model, 3 – blow-up to infinity, 4 – difference between Model and global population data, enlarged 5 times showing the losses during World Wars, ° – 1995

the global transition. The narrowing is typical for interactive nonlinear dynamic systems and on its own indicates the existence of the global interaction, introduced to explain global population growth, an interaction involving the exchange and propagation of information throughout the global system. In the case of the population transition one sees how this interaction affects the demographic development of billions of people. In a basic and profound way the procreation of the largest communities in the world at very different stages of development are changing and now passing through a decisive transformation.

5. The world of the future

5.1 Population

Estimates of the future population of the world made by the Model show that the population is to asymptotically level out at 10 to 12 billion. The same numbers are suggested by demographers using basically different methods and assumptions in their forecasts, a correspondence that is encouraging [15]. It is of interest to discuss the long-term changes that can be expected in the world as it passes into a new stage of development after the transition. In practical terms all growth will happen in the developing world by the end of 21st century and will be accompanied by a drastic change in the age structure and a lowering of the total fertility rate (TFR). There are good reasons to expect that this ultimate state will be stable, although in the years left some large scale migrations and social disruptions may yet occur.

Up to 1915 within a ± 5% error the model population follows the data from demographic surveys [16]. During the World wars, which at this time scale merge, indicate an 8% global population decrease. The integrated losses during this fateful period were 11 000 million people x year and, assuming a life expectancy of 40 years the losses are ~ 280 million. Reported losses in action were 50 million, and 50 million are the losses due to the pandemic Spanish flu that hit the impoverished world. After this fateful time population by 1975 returns, with a brief overshoot, to the unperturbed numbers to finally break away from the hyperbolic growth curve since 1965.

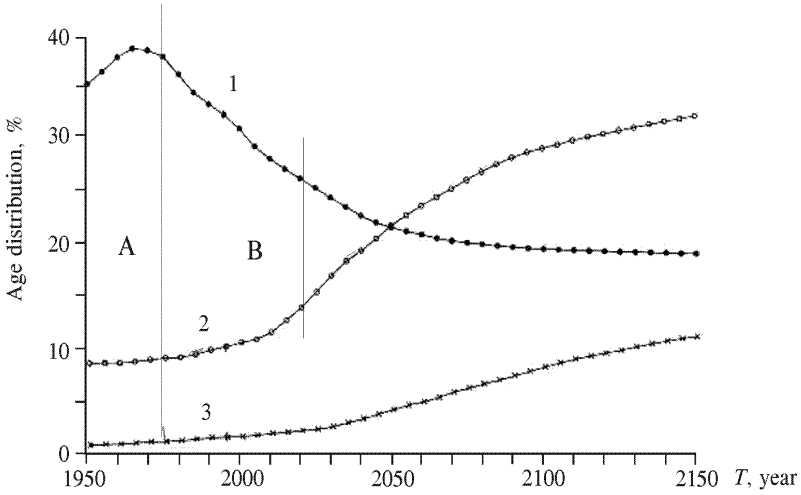

Figure 4. Change in age distribution for the global population 1950 – 2150
1 – age group less than 14 years, 2 – group older than 65 years, 3 – group older than 80 years.
A – distribution in developing countries, B – distribution in developed countries in 2000

The most significant current change in the developed countries is the low total fertility rate. For a stable population demographic sustainability means 2.1 – 2.15 children for each woman. At present, in developed countries the TFR is 1.12 – 1.15. In other words each woman should have one child more otherwise these societies demographically are not sustainable. If this trend does not change these societies are heading for extinction, a point discussed by Buchanan [17].

In the modern world a significant increase in the number of migrants is seen. Two centuries ago Europeans emigrated to America, Africa and Australia, in the case of Russia – to Siberia. Now an opposite trend is dominant, compensating the low TFR in developed countries. The migrants with a higher TFR are winning 'the war of the wombs', which leads to complex social problems and a change in the ethnic composition of nations.

The developed countries are already at this final stage and in recent developments one can discern the features of a future world with a stabilised population. In this world numerical growth, primarily expressed by population growth, will no longer dominate. The connection between population growth and the square of global population will cease to express development. In this case there are two alternatives: one is stagnation of development in a world of zero growth. The other is to find a new dimension for development, and, as the quantitative growth of the past is gone, there is a possibility for qualitative growth and development. At present in developed countries there is a significant shift of the workforce from the production sector to services: health, education, science, and leisure indicating the shape of things to come.

5.2 Ageing

As the population of the world will grow no longer, the number of older people will outnumber the young. This is an essential result of the demographic transition, already seen in developed countries, where societies are getting much older [15]. The restructuring of the age pyramid, a rapid and profound transition to a stable global population, will inevitably lead to far-reaching changes in many aspects of life, including global security, social and economic support of the old. Inevitably it will demand means to support the older generations, leading to greater expenditures for health services. Probably one can expect that society will gainfully use the expertise of the old, even returning the extended family. The post-transition age structure will result in the development of new values in society, now lacking the impact to growth of

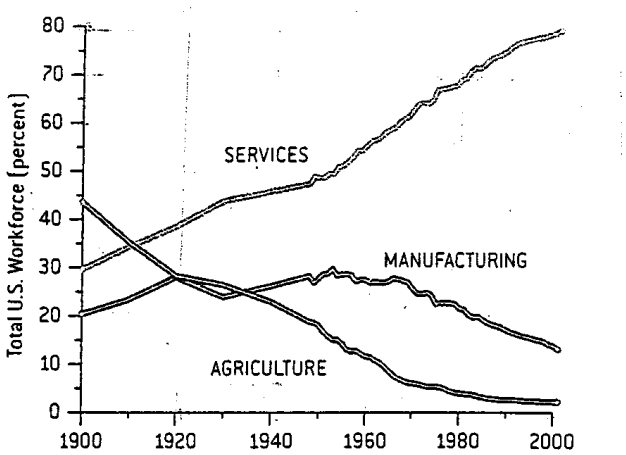

Figure 5. Deindustrialization: Changes in total U.S. workforce in 20th century (in %)

human numbers, changes that can be expressed as the challenge in pursuit of a *quality of life* expressed by *human capital*. As a consequence of the very rate of the transition, society is now in a state far from equilibrium. In these conditions, when there is no time for the adjustment of the social infrastructure, growing disruptions can be expected both in the disparity of wealth and misery, in access to education and at a personal level in the stress and strain of modern life, in the family and society at large.

The high divorce rate, criminality, collapse of law and order, of long established moral values, may be traced to this rapid rate of change, also contributing to the low TFR in the developed world. At a different scale this can also be seen in the disintegration of empires and the breakdown of governance [18]. This is seen in the realm of ideas and philosophy, in much of modern art, with no time for values and tradition to establish them. It is expressed in the short range of socially relevant ideas and lack of long term commitments. Even modern science is caught in this competitive market-driven rat race with its short-range priorities.

These disruptions exclude long-term planing and socially relevant developments in a world dominated by short-range forces. The crisis of the UN system, which has not changed in more than 50 years, may also be attributed to this transitory stage of world history [25]. It may be simplistic to explain these facts of modern life in such terms, but definitely a significant contribution of the transition should be taken into account in projecting the global future in pursuit of a new social order.

5.3 Economic development

The model equates the rate of growth to the development of the population system, seen as a function of the global population. Thus the production function of the global economy is the square of the total number of people. As an essentially non-linear function it is not what would be expected in an economic system, usually assumed to be in the first approximation linear and additive, with a relatively slow process of growth and the reversible exchanges in a market. The non-linear interaction is both dominant feature of the system, determining, or rather moderating growth justifies this point of view. It should also be kept in mind, that information should not be treated as an ordinary economic entity, a commodity, and exchanged as any other product. Its multiplicative and irreversible nature leads to pronounced difficulties in accepting the concept of intellectual property in a market economy. One of the issues is how this information is generated by science and supported by society, and how it is distributed and multiplied in the course of education, taking up more and more time in human life.

The quadratic term was decisive in determining growth all through our history and expresses the contribution of the informational component to the global production factor. This can be seen as the domination of the 'software' of global development, input, which is associated with culture, science and all those factors, like co-operation, communication, consciousness and memory in contributing to the meta-economic growth of mankind. As the principle factor of growth it indicates the primacy of the collective processes in society, which we owe to our highly developed brain and mind, the main and peculiar characteristic of *Homo sapiens,* and expressed by established morals and ethical behaviour of society,

The model suggests that information is not a minor component of macroeconomics, but in global meta-economics it is becoming the controlling factor of growth. In the emerging information and knowledge society a new set of values and priorities will develop, which can have a significant impact on our future, changing attitudes towards the environment, consumerism, population growth and control, and the quality of life itself.

Neo-classical economic theory does not really take into account the 'software' component in constructing models of development, being mainly occupied with an understanding of how the 'hardware', industry and agriculture in the first place, works and generates wealth. In the case of a knowledge economy it seems that the fundamental reason for development and growth is this 'software' component. In developments of economic theory, pioneered by Max Weber and later by Josef Schumpeter, it is now acknowledged that in the non-equilibrium conditions of economic growth social 'software' has to be seen as the main driving force. The extensive time devoted to education 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 for the time spent on education is one of the reasons for a low TFR in developed countries. Although in a complex interactive non-linear system one should be careful in identifying the principal factors affecting growth, the following observation by Fucuyama is of interest: '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' [19].

The future is seen by many as an information-dominated society [20]. Can this lead to a fundamental transition, to a new awareness, a global consciousness to be realised by a communication system, like the Internet? Could it be conjectured that such a system would evolve, and finally self-organize itself into a qualitatively new informational entity, with a knowledge-based superstructure for our common future?

5.4 Resources

In the foreseeable future in a world with a stabilized and stable future population of some 10 to 12 billion there will be enough resources to provide support for a sustainable global population system within the main assumptions of the phenomenological theory. The lack of any immediate effect of resources, other than generalized information, is a point that needs to be discussed, for it contradicts conventional Malthusian wisdom, epitomized in the first Reports to the Club of Rome [21, 22]. They were the first to draw worldwide attention to global problems, although growth of population was not explicitly coupled to development. If the global population system had pursued its self-similar pattern of growth, as is did throughout the ages, then our numbers in 2006 would be 10 billion and not 6.5 billion. Still, in the future mankind could reach a stage of development when resources could limit growth, although this is off limits of the model.

The distribution of the population world-wide is very far from uniform. If there were a general lack of resources, then the first reaction would be a much more uniform distribution of population than the one seen. If in the past there have been massive movements of people, at present migrations throughout the world affect less than 0.1% of the global population in a year, a flux smaller by an order of magnitude than the annual increase of the population of the world. This can indicate that globally there are enough resources, and any local lack may be ascribed to conditions of war, disruption of society, often caused by a local blow-up of population, as a result of the population transition. A disparity in the population distribution and resources is what matters, and it is there that most current economic, political and military problems appear.

In matters of food resources it is instructive to compare India and Argentina. The area of Argentina is 30% less than that of the subcontinent, but the population of India, now greater than one billion, a country with an ancient civilisation, is 30 times larger than that of Argentina, where modern development began 200 years ago. But Argentina, with its great agricultural resources, in principle, could feed the whole world. It should also be noted that at present both China and India have all necessary supplies of food. Thus, the self-similar global pattern of the development of mankind definitely shows that globally there are enough resources that do not fundamentally limit population growth and be the Malthusian reason for global demographic trends and the transition. The breakdown of the distribution of food and development is happening in many countries of Africa. There the population explosion with the consequent lack of social development leads to a 'poverty trap', when population growth overtakes economic development. In these developing countries at present this as a greater threat to security, than the perceived lack of resources.

In discussing the long term energy future of our planetary civilization much is said about the impact of energy and industry, the life support system of civilization on the global environment. For some the environment is becoming of even greater significance than population, to the extent that an environmental imperative is pronounced, although all through human history population has dominated at the cost of great degradation of the environment. For example, the environment of most of Europe is no longer natural. Even bigger is the impact of civilization in China with its very high density of population, living along its great rivers in an artificial, but stable and sustainable environment over the ages. These conditions of life are far from those practiced in Europe, but they have been sustained in one of the oldest, if not the oldest continuously recorded civilization, now undergoing remarkable development. The impact of the development of China and India on the immediate future will be immense and rapid.

If one assumes a consistent systemic point of view, in that case the growth of human numbers will be determined by global population dynamics, driven by the priorities of the population imperative. This does not mean that nothing can or should be done for Vilfredo Pareto remarked that 'Human nature may be governed only by following it'. For our behavior at large is an expression of systemic development, statistically adding up into global growth. Following a systems approach in an integrated treatment of global population growth these issues are taken into account. As far as all previous history is described by the model, the only thing left is the extent to which this treatment can be projected into the future and when, if ever, it is to break down. In other words, will the demographic imperative, expressed by the model and tested by the past, stand the test of time in the future, and if not, where are its limits?

One of the most critical issues will definitely be the total fertility rate and its impact on migration and the future growth rates of the countries we now call developing. The case of Japan and South Korea show that these countries rapidly lost their vitality.

5.5 Sustainability

After the Rio 1992 and Johannesburg 2002 International Conferences the concept of sustainable development has been put forward. The idea of sustainability was mainly developed in the Gro Brundtland's report «Our common future» (1987) and is formulated 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. All history has unequivocally shown that the growth of population had precedence over the environment. Mostly under economic pressure people moved and resettled, migrated to other parts of the world in search of space and resources. What really matters and creates the disparities and misery, are not a global lack of basic resources, but their distribution. In a stabilised world with a slowing down of development, a new ecological consciousness may appear, with outspoken criticism of consumerism.

At the same time the developing world is experiencing rapid economic growth, urbanisation and growing regional tensions of wealth and poverty. It is difficult to expect that these countries will follow the demands of sustainability, as they are seen in the West, and change their pattern of development in energy and their impact on the global environment. This can hardly happen before they go through a phase of extensive development to a stabilised population during the demographic transition.

5.6 Globalisation

These new processes of development are accompanied by an internationalisation of finance and technology. The rapid transfer of information and money has become the principle feature of globalisation and now the Internet and the mass media are the main instruments of change and influence. On one hand, in a world where globalisation has become an imminent and dominant feature, the opposing trend of cultural diversification is manifest. This may be seen as the confrontation of the 'hardware' of civilisation with the 'software' of culture, which was always present all through the growth and development of mankind. Today, in a world where the rate of numerical growth has reached its absolute maximum and mankind is passing a decisive threshold in its development, these strains and inequities could result in major conflicts in the rapidly growing countries of the developing world.

On the other hand, one has to keep in mind that the process of globalisation began long ago. For example science, fundamental science, right from its beginning was a global enterprise. Before that the main religions, known as world religions, were since the 'axial time' global, just as languages, by their common roots are seen as global phenomena. Culture and knowledge were, within the capacity of past civilisations, practised globally to an extent not usually recognised, being overwhelmed by recent events. These trends are discussed in detail in «Caring for the future. Making the next decades provide a life worth living (1996)» [23], written by The independent commission on population and quality of life, chaired by Maria Lourdes Pintasilgo, the former Prime Minister of Portugal. In Gro Brundtland's report on the environment, it was explicitly stated that 'we need a transition from quantity to quality'.

The report on the quality of life recognises the profound transition being experienced by civilisation and the change in attitudes and values it is to bring. It emphasises the necessity to develop an understanding of these global issues: for only with the appearance of stronger socially oriented governments and the emergence of

global governance can these problems be resolved. The report assures 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 the pollution of the atmosphere, changing the technology of industry and modifying the human demands on energy, encouraging energy saving measures. But only by a basic change in governance on a global scale, can these visions be realised. The report outlines a positive future and in no way shares the apocalyptic pronouncements of latter day Cassandra's.

Humanity is now passing through the demographic revolution from an information moderated society to an information-dominated global knowledge society [24]. Finally, a new set of values in a world will emerge, where numerical growth will cease to form our mentality. The future in the post-industrial world will be determined not by the production of food or energy, by the hardware, but by the software of our global population system. It is not the volume of production that matters, but the way these results of the industry are distributed. In other words, the problem will be not the integral of the distribution functions, but how the distribution is executed in the global system. This is to happen in an economy with a zero growth of human numbers in a society with the predominance of older people.

These are the boundary conditions for the future. In this future, human capital of an educated society will, hopefully, lead to establishing norms of social values. It will be determined more than ever by education and the attitudes and values propagated by the mass media. The mass media, in the first place television, has yet to recognise its responsibility for its influence on social capital and in taking culture seriously. In the post-transitional society a factor of primary importance will be education, taking up more time and effort than at any other period in the history of humankind. At present in developed countries lifelong education has become a reality and the education industry is a major and growing sector of the economy.

5.7 Security

In the foreseeable future armies will change. In countries that have passed through the transition there are fewer demographic resources to man the huge armies of the recent past by conscription. On one hand, the low growth rates and stagnant populations do not create conditions for conflict, for large-scale world wars, as happened in the recent past. High technology has changed the character of arms in modern warfare and in spite of all the arrogance of power has shown the futility of might. Could then the mission of these new armed forces be the containment of peace, controlling migration, fighting organized crime and terrorism, rather than war leading to territorial gains and a 'new world' order?

The last sources of a real large-scale conflict are countries passing through the demographic transition at its explosive stage, expressed by terrorism. The paradox of fighting terrorists by regular forces of 'civilization' can be seen as the confrontation of a hierarchical structure with a network held together by culture. Could this lead to conflicts, a 'clash of civilizations' war between Islam and Christianity? Or should this be resolved by dialogue, by the 'software' of politics, rather than by force? The Islamic world is somewhat lagging in its economic development and modernization, in part for cultural reasons. On the other hand the rapid and remarkable growth of China and India shows how fast these changes may be, with a profound impact on the world picture seen at large. But rapid growth may result in the loss of stability and security, as it happened in Europe, triggering off the World wars, a lesson of history worth recalling [25].

6. Conclusions

For the population of the world the theory provides a description of the gross features of the growth and evolution of humankind. Over the entire course of development a constant trend in the growth of human numbers is discerned that follows a self-similar pattern of growth, expressing the dynamic invariance of development. The inherent limits for growth are determined not by resources or space, but by the mechanism of growth and development non-linearly coupled and mutually determining the pace of history.

A decisive step was to identify the global population not as a mere sum of all countries, but as an entity, as a dynamic system. This and the recognition of the collective nature of the interaction, driving the growth of the global population, were essential. These connections became the main factor in uniting people in organizing their cooperation synchronizing development and setting up common patterns of action. In this context information should really be seen as a generalization, as the factor statistically summing up all contributions to growth of an economic, cultural and biological nature in the human story. The idea of a summary interaction is drawn from physics and modern developments in non-linear studies of complex systems, and these concepts are not generally known to social scientists, economists and global modelers that now have to accommodate to this exercise in interdisciplinary research. In this case mathematical models may provide new instruments for analysis.

The model is justified not only by the extent to which the results of modeling correspond to the facts of life, but also by the fundamental principles of systemic growth. The concept of self-similar growth is an expression of systemic dynamics and is now applied to the description of global population growth. When depicting the overall process of development by an essentially non-linear model it should be kept in mind that it cannot be directly applied to local or regional growth, for we are dealing with a collective interaction. But the global process of development definitely does influence all regions by the connections and interactions implied in the model and acting in the world.

The model indicates that mankind is now rapidly passing through a critical period of the global demographic revolution. The demographic revolution is an event of great significance, and in the story of mankind it far surpasses the Neolithic revolution and all others known in history, ranking in its importance with the emergence of *Homo*, endowed with a mind and consciousness. Only an anthropologist of the future shall have a chance of understanding the magnitude of the transition and assessing the changes, which mankind is to experience. He will have to wait a hundred years to make his judgement, not the million years, which have passed since the early stages of our origins. Some historians have pronounced the end of History [26]. Today we are witnessing a much more profound transformation; a crucial period compressed into a remarkably short time of global change.

The 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. The numbers, the ‘hardware’ of our world are changing faster than the social conditions; the global ‘software’ has no time to keep up with the pressure of the environment and technological development. With the demographic revolution a new set of values could emerge, expressing the change from quantitative growth to qualitative development. The nature of this imminent transformation is yet to be fully understood and its consequences assessed. This can be seen as the challenge facing

science and the humanities in the modern world. Moreover, it is not yet obvious that in a world where numerical growth is de-coupled from development, whether humanity will take up the path of qualitative growth, or evolve into a pattern of slow development, even becoming stagnant, and, finally decaying. A critical issue is the marked decrease of the total fertility rate in the developed world. It is definitely not a matter of wealth but of values, of altruism, morals, which will have to be rediscovered. The decrease in TFR could be a reaction to the demographic revolution itself, a transient phenomenon and, as the post-transition society of zero growth will be established, the TFR could return to its sustainable level. This possibility is of great significance for the future of mankind.

The extent of the difficulties of controlling complex demographic systems, demographic practice has repeatedly shown that these problems are not only complex, but any direct intervention is not always productive. To exercise an effective global demographic policy, apart from general medical and educational programs, practiced by national and a number of international organizations, and taking into account that major changes are to happen in the next decades, the global transition will be determined more by nature rather than by policy.

In this study the demographic factor is taken to be decisive. As these discussions excite high feelings on matters concerning our common future and the issues at stake are great, it is most necessary to develop and foster interdisciplinary research, following 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. It is no accident that demographic data should be the first object where a definitive step can be made in working out a model, which can apply methods of exact sciences to society.

At this point it is proper to inquire what could be the next step in the evolution of mankind. At first, it may seem that nothing has to be done, as the global population system will look after itself, including the development of our own attitudes towards these issues. On the other hand, what is the extent to which mankind can take over guidance of its own future? This involves profound moral issues and much depends on the limits of our knowledge, reasoning and responsibility. According to the conjectured interpretation of the global interaction as an expression of our consciousness, of the social consciousness of mankind for that matter, new possibilities are open. Could this include our capacity to develop social technologies and change the limits of human nature, the human genome in the first place as it probably once happened?

Up to the present the biology of the human race has not changed and was determined by nature. Now there is a possibility to interfere and moderate the biology, the genetic make-up of mankind, as humanity itself can become a conscientious actor. It may well be that these factors are to limit the extent of the model and at the same time indicate the agents for change which 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.

In the foreseeable future we can hardly expect to sensibly influence and change the overall pattern of growth. With the sheer size of the world 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. The fundamental understanding of growth is still rather limited and definitive advice for action is hard to provide, apart from the very general recommendations, which lead to current demographic policies. Probably the most important issue is by all means to ensure the

stability and security of the world to be, as the prerequisite for resolving global problems.

This essay is the outcome of an effort to develop interdisciplinary understanding in an attempt at bringing together ideas and methods coming from areas of research long separated by tradition and history. As the model is supported by further research and the insight it provides gains ground, this should lead to greater understanding of the present state of world affairs. It may offer a common frame of reference for anthropology and history, demography and sociology, for studies in human evolution and genetics. For economists it provides a general framework for assessing our development. For doctors and politicians it can indicate the sources of stress and tension in this transient period, unique throughout all human development, affecting both the individual and society in terms of personal and global security and stability. In the emerging world of a stabilised global population there will be a lot of restructured time to resolve these problems of our own making, hopefully managing them without a major disruption. This may provide us with some optimism in facing the predicament of mankind and a greater understanding of the present state of the world and its foreseeable future.

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APPENDIX: A BRIEF DESCRIPTION OF THE MATHEMATICAL MODEL

Types of growth

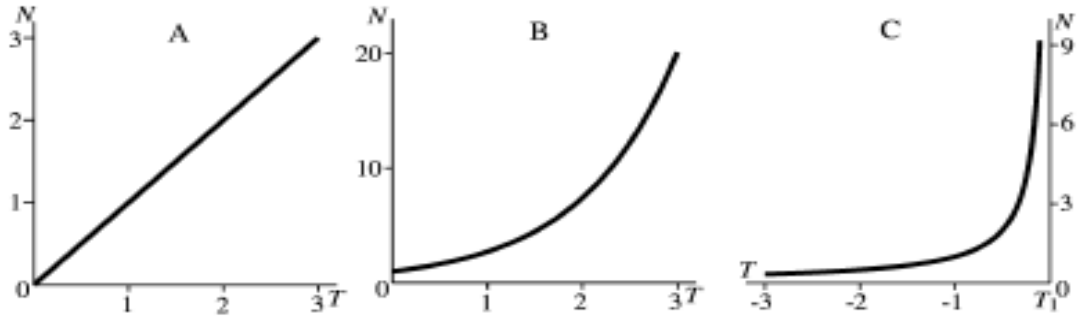

Figure 6. Linear $N = AT$ Exponential $N = \exp(T/\tau)$ Hyperbolic $N = C(T_1 - T)^{-1}$

In the following a brief description of the basic mathematics of the global model is outlined [1,2]. It was long recognised that the growth of the global population may be described with remarkable accuracy by an empirical formula:

$$N = \frac{C}{T_1 - T} = \frac{200}{2025 - T} \text{ Billions.} \tag{1}$$

It was rejected by most demographers as it led to a runaway singularity at 2025, to a divergence in the past, and did not take into account local social and economic conditions in different countries. But according to a global approach this is a valid asymptotic self-similar expression, when growth is determined by the intrinsic process of development, driven by the collective global interaction:

$$\frac{dN}{dt} = \frac{N^2}{K^2} \tag{2}$$

meaning that the growth rate $\frac{dN}{dt}$ is equated to development $\frac{N^2}{K^2}$. In (2) time $t = \frac{T - T_1}{\tau}$ is expressed in units of $\tau = 45$ years, characterising the human life span, and $K = \sqrt{C/\tau} = 62000$ is the main dimension-less large parameter, determining growth and all numerical results of the theory.

The expression for development states that growth depends only on the total number of people in the world, on *N*. It is a function – the square – of the number of people, an expression that may be seen as a binary interaction similar in its nature to the Van-der-Waals interaction in the statistical theory of non-ideal gases and other many-particle systems, or as the network complexity of the global population. In the first approximation this essentially non-linear relationship (2) leads to the singularities and asymptotic blow up of the global population in year $T_1 = 2025$. In the next approximation a cut-off with a characteristic time of τ years is introduced into (3a) to get rid of the run-away singularity and describe the passage through the demographic transition:

$$\frac{dN}{dT} = \frac{C}{(T_1 - T)^2} \quad (3a), \qquad \frac{dN}{dT} = \frac{C}{(T_1 - T)^2 + \tau^2} \ . \tag{3b}$$

By integrating (3b) the passage through the demographic transition may then be described by:

$$N = \frac{C}{\tau} ctg^{-1}\left(\frac{T - \overline{T}_1}{\tau}\right) = K^2 ctg^{-1} t \qquad \text{(See Figs.1and 5)} \tag{4}$$

The constants K and τ are determined by fitting (4) to world population data. These expressions describe growth before and after the demographic transition, lead to a shift of

$T_1 = 2025$ to $\overline{T}_1 = 2000$ and determine the asymptotic limit of the global population in the foreseeable future:

$$N_\infty = \pi K^2 = 12 \text{ Billion} \tag{5}$$

At $\overline{T}_1 = 2000$ the population is $N_1 = 1/2 N_\infty = 6$ Billion and reaches its maximum growth rate:

$$\left(\frac{dN}{dT}\right)_{MAX} = \frac{C}{\tau^2} = \frac{K^2}{\tau} = 86 \text{ Million per year.} \quad \text{(See Fig.2)} \tag{6}$$

Calculations for populations and projections agree, within the accuracy of the data, with estimates made by anthropologists for the past and data by demographers for the next 200 years. These expressions only apply to the global population of the world *N* and cannot be used to describe any subsystem or country. The asymptotic hyperbolic singularity in the past is eliminated in a similar way and, with the same time constant, leads to an estimate of the beginning of the human story, which corresponds, with the time of the possible crucial mutation in our past:

$$T_0 - \overline{T}_1 = K\tau\pi / 2 = \tau\sqrt{N_1 \pi / 2} = 4.5 \text{ Million years ago} \tag{7}$$

and the consequent arrival of the tool-making *Homo habilis* 1.6 Million years ago.

By integrating the population from T_0 to $\overline{T}_1$ the number of people who ever lived:

$$P_{0,1} = 2.25 K^2 \ln K = 100 \text{ Billion} \tag{8}$$

may be calculated. Each of the $\ln K = 11$ exponentially spaced periods of prehistory and history match in detail the gross time-table of the human past, when during each period 9 billion people lived. The Neolithic, when people invented agriculture and began to aggregate into villages and towns, occurred on the logarithmic time scale at the halfway point. By that time – some 10 000 years ago – half of all people who ever lived had inhabited the world.

In a hyperbolically growing population the instantaneous exponential time of growth is not a constant and changes as the age of the epoch:

$$T_e = \overline{T}_1 - T \,. \tag{9}$$

Thus, a 100 years ago the global population grew at a relative rate of 1% per year. In the lower Paleolithic a million years long, the population would change within a million years due to the exponential expansion of the time scale in the past. In this case the time from the end of a period to the demographic transition at $\overline{T}_1 = 2000$ is equal to half the duration of the period. For example, since the end of lower Paleolithic half a million years have passed and since the Middle ages, which were 1000 years long, 500 years have gone. As the critical date is approached, the time scale can be compressed no more. The global population system then rapidly switches over to a basically new pattern of zero growth that, in the framework of the model, is asymptotically stable. The transitions during growth are interpreted as phase transitions in an evolving and self-organising system of great complexity, governed by the parameter of order N, the strongest being the global demographic revolution, which is $2\tau = 90$ years long.

The main equation determining growth (2) describes the average growth of the global population and, as time is averaged over the past, it implies a memory in the process of growth and development. As the growth rate is proportional to the square of the global population this process of development is irreversible, non-additive and non-linear. The equation for growth does not have terms accounting for the distribution of population in space. This means that the effective global interaction is non-local, spans the globe and is responsible for the synchronous world-wide development of mankind, shown in the Table. All shorter periods and processes of tribal origin and historic development are local and have all the elements of dynamic chaos. They are not explicitly taken into account, but they contribute to the stability of the gross process of deterministic average growth.

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The theory of Sergey Kapitza is a new synthesis based on the integrative tradition of Russian thinking. It provides for an objective understanding of global problems facing humanity at a critical phase in development.

Nobel prize winner Jores Alferov,
Ioffe Physico-Technical Institute, St Petersburg, Russia

The astounding elegance of Sergey Kapitza's new paradigm integrates human values and culture with "demography as destiny" reaffirming that truth and beauty are two sides of the same coin. A major breakthrough, which will transform the ongoing debate on growth and prospects for humankind.

Professor Mihaljo Mesarovic,
Case Reserved University, Cleveland, USA

A splendid treatise of population dynamics, based on rigorous mathematical understanding.

Professor Ernst von Weizsaecker,
Dean, Bren Environment School, University of Santa Barbara, USA.

Only one author with his vast and exceptional experience in popularisation of science could develop in such an original way global population dynamics, where rigour and communication ability go hand in hand. I fully share the cultural approach of Sergey Kapitza: each unique human being is able to think and to create. This distinctive faculty makes behaviour unpredictable, and, therefore, hopeful.

Professor Federico Mayor,
Director – General of UNESCO (1987 – 1999), *Spain*

Kapitza's analysis shows that a profound transformation is imminent. We are to live through it and anticipating the challenge of change can help to react accordingly. But what will all this lead us to?

Professor Franz-Josef Radermacher,
University of Ulm, Ulm, Germany

The main contribution by Sergey Kapitza is that he not only treats the whole population of the world as a global entity, but also very successfully applies this principle in his research and forecasts.

Andrew Kokoshin, Member, Russian Academy of Sciences,
Dean, Department of Global Politics, Moscow State University, Russia

Discoveries in humanities and social sciences are, indeed, rare and the book by Kapitza on global demography is such an event. The laws of growth of human numbers were discovered by developing a novel approach in a quantitative approach to social studies. The model describes the growth of the entire population of our planet by a universal law applicable to all stages of human history. For the current century Kapitza's insight has socio-cultural, economic and political consequences of great importance.

Viacheslav Stepin, Member, Russian Academy of Sciences,
Director, Institute of Philosophy (1987 –2006).