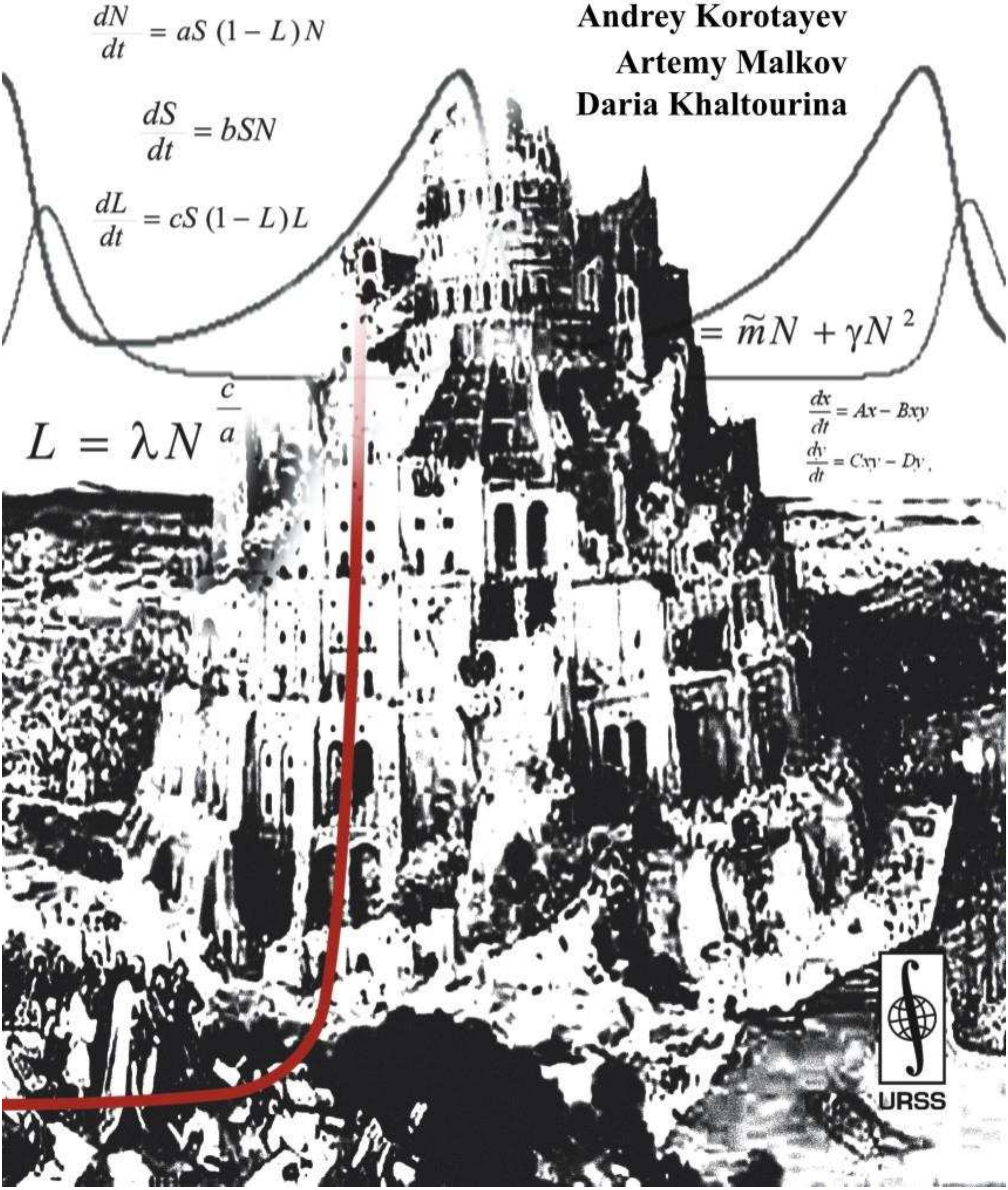
INTRODUCTION TO SOCIAL MACRODYNAMICS

Secular Cycles and Millennial Trends

Andrey Korotayev
Artemy Malkov
Daria Khaltourina



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Moscow: URSS, 2006

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Human society is a complex nonequilibrium system that changes and develops constantly. Complexity, multivariability, and contradictions of social evolution lead researchers to a logical conclusion that any simplification, reduction, or neglect of the multiplicity of factors leads inevitably to the multiplication of error and to significant misunderstanding of the processes under study. The view that any simple general laws are not observed at all with respect to social evolution has become totally dominant within the academic community, especially among those who specialize in the Humanities and who confront directly in their research the manifold unpredictability of social processes. A way to approach human society as an extremely complex system is to recognize differences of abstraction and time scale between different levels. If the main task of scientific analysis is to detect the main forces acting on systems so as to discover fundamental laws at a sufficiently coarse scale, then abstracting from details and deviations from general rules may help to identify measurable deviations from these laws in finer detail and shorter time scales. Modern achievements in the field of mathematical modeling suggest that social evolution can be described with rigorous and sufficiently simple macrolaws.

The first book of the *Introduction* (*Compact Macromodels of the World System Growth*. Moscow: Editorial URSS, 2006) discusses general regularities of the World System long-term development. It is shown that they can be described mathematically in a rather accurate way with rather simple models. In this book the authors analyze more complex regularities of its dynamics on shorter scales, as well as dynamics of its constituent parts paying special attention to "secular" cyclical dynamics. It is shown that the structure of millennial trends cannot be adequately understood without secular cycles being taken into consideration. In turn, for an adequate understanding of cyclical dynamics the millennial trend background should be taken into account.

Contents

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Needless to say, faults, mistakes, infelicities, *etc.*, remain our own responsibility.

Introduction: Millennial Trends[1]

In the first part of our *Introduction to Social Macrodynamics* (Korotayev, Malkov, and Khaltourina 2006a) we have shown that more than 99% of all the variation in demographic, economic and cultural macrodynamics of the World System over the last two millennia can be accounted for by very simple general mathematical models. Let us start this part with a summary of these findings, along with some relevant new findings that we obtained after the first part of this *Introduction* had been published. This summary is intended for all those interested in patterns of social evolution and development, including those who are not familiar with higher mathematics. Accordingly, we have included some basic material that mathematically sophisticated readers may wish to skip over lightly or entirely ignore.

In 1960 von Foerster, Mora, and Amiot published, in the journal *Science*, a striking discovery. They showed that between 1 and 1958 CE the world's population (N) dynamics can be described in an extremely accurate way with an astonishingly simple equation:[2]

$$N_t = \frac{C}{t_0 - t}, \qquad (0.1)$$

where N_t is the world population at time t, and C and t_0 are constants, with t_0 corresponding to an absolute limit ("singularity" point) at which N would become infinite.

Parameter t_0 was estimated by von Foerster and his colleagues as 2026.87, which corresponds to November 13, 2006; this made it possible for them to

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[1] This book is a translation of an amended and enlarged version of the second part of the following monograph originally published in Russian: Коротаев, А. В., А. С. Малков и Д. А. Халтурина. *Законы истории: Математическое моделирование исторических макропроцессов (Демография. Экономика. Войны)*. М.: УРСС, 2005.

[2] To be exact, the equation proposed by von Foerster and his colleagues looked as follows: $N_t = \frac{C}{(t_0 - t)^{0.99}}$. However, as has been shown by von Hoerner (1975) and Kapitza (1992, 1999), it can be written more succinctly as $N_t = \frac{C}{t_0 - t}$.

supply their article with a public-relations masterpiece title – "Doomsday: Friday, 13 November, A.D. 2026".[3]

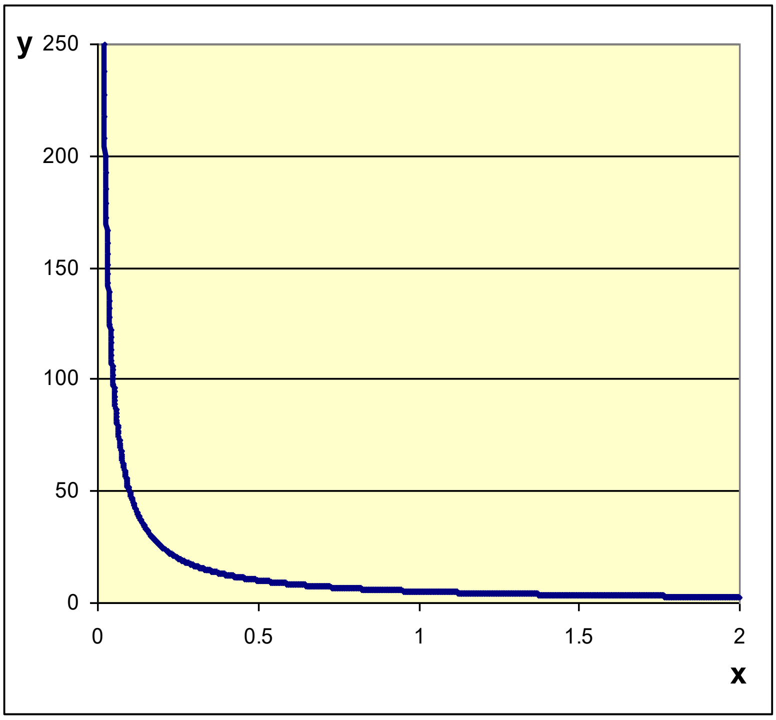
Note that the graphic representation of this equation is nothing but a hyperbola; thus, the growth pattern described is denoted as "hyperbolic".

Let us recollect that the basic hyperbolic equation is:

$$y = \frac{k}{x}\,. \tag{0.2}$$

A graphic representation of this equation looks as follows (if *k* equals, *e.g.*, 5) (see Diagram 0.1):

Diagram 0.1. Hyperbolic Curve Produced by Equation $y = \frac{5}{x}$



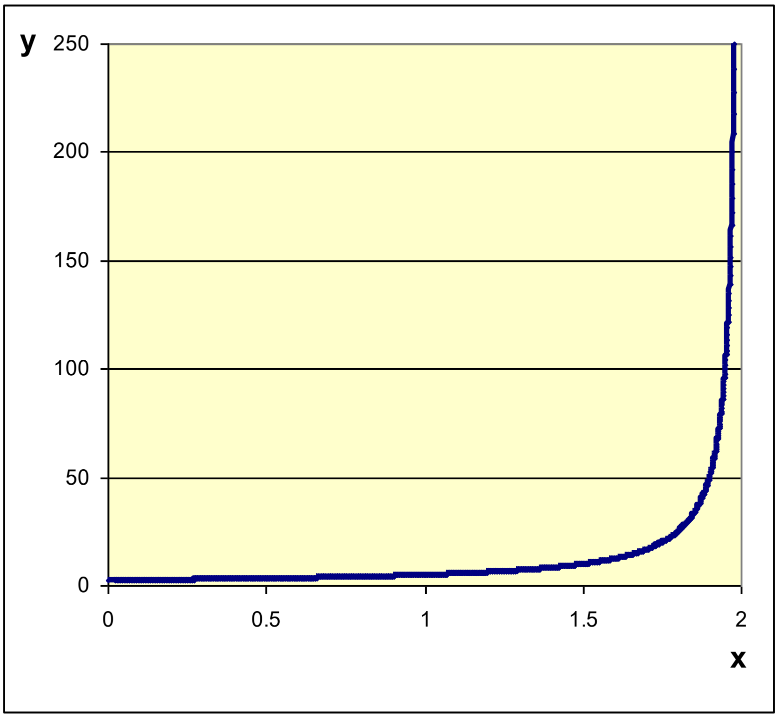
[3] Of course, von Foerster and his colleagues did not imply that the world population on that day could actually become infinite. The real implication was that the world population growth pattern that was followed for many centuries prior to 1960 was about to come to an end and be transformed into a radically different pattern. Note that this prediction began to be fulfilled only in a few years after the "Doomsday" paper was published (see, *e.g.*, Korotayev, Malkov, and Khaltourina 2006a: Chapter 1).

The hyperbolic equation can also be written in the following way:

$$y = \frac{k}{x_0 - x}. \qquad (0.3)$$

With x_0 = 2 (and k still equal to 5) this equation will produce the following curve (see Diagram 0.2):

Diagram 0.2. Hyperbolic Curve Produced by Equation $y = \frac{5}{2 - x}$



As can be seen, the curve produced by equation (0.3) at Diagram 0.2 is precisely a mirror image of the hyperbolic curve produced by equation (0.2) at Diagram 0.1. Now let us interpret the *X*-axis as the axis of time (*t*-axis), the *Y*-axis as the axis of the world's population (counted in millions), replace x_0 with 2027 (that is the result of just rounding of von Foester's number, 2026.87), and replace k with 215000.[4] This gives us a version of von Foerster's equation with certain parameters:

$$N_t = \frac{215000}{2027 - t}. \qquad (0.4)$$

In fact, von Foerster's equation suggests a rather unlikely thing. It "says" that if you would like to know the world population (in millions) for a certain year, then you should just subtract this year from 2027 and then divide 215000 by the difference. At first glance, such an algorithm seems most unlikely to work; however, let us check if it does. Let us start with 1970. To estimate the world population in 1970 using von Foerster's equation we first subtract 1970 from 2027, to get 57. Now the only remaining thing is to divide 215000 by the figure just obtained (that is, 57), and we should arrive at the figure for the world population in 1970 (in millions): 215000 ÷ 57 = 3771.9. According to the U.S. Bureau of the Census database (2006), the world population in 1970 was 3708.1 million. Of course, none of the U.S. Bureau of the Census experts would insist that the world population in 1970 was precisely 3708.1 million. After all, the census data is absent or unreliable for this year for many countries; in fact, the result produced by von Foerster's equation falls well within the error margins for empirical estimates.

Now let us calculate the world population in 1900. It is clear that in order to do this we should simply divide 215000 million by 127; this gives 1693 million, which turns out to be precisely within the range of the extant empirical estimates (1600–1710 million).[5]

Let us do the same operation for the year 1800: 2027 – 1800 = 227; 215000 ÷ 227 = 947.1 (million). According to empirical estimates, the world population for 1800 indeed was between 900 and 980 million.[6] Let us repeat the operation for 1700: 2027 – 1700 = 337; 215000 ÷ 337 = 640 (million). Once again, we find ourselves within the margins of available empirical estimates (600–679 million).[7] Let us repeat the algorithm once more, for the year 1400: 2027 – 1400 = 627; 215000 ÷ 627 = 343 (million). Yet again, we see that the result falls within the error margins of available world population estimates for this date.[8] The overall correlation between the curve generated by von Foerster's

[4] Note that the value of coefficient k (equivalent to parameter C in equation (1)) used by us is a bit different from the one used by von Foerster.

[5] Thomlinson 1975; Durand 1977; McEvedy and Jones 1978; Biraben 1980; Haub 1995; Modelski 2003; UN Population Division 2006; U.S. Bureau of the Census 2006.

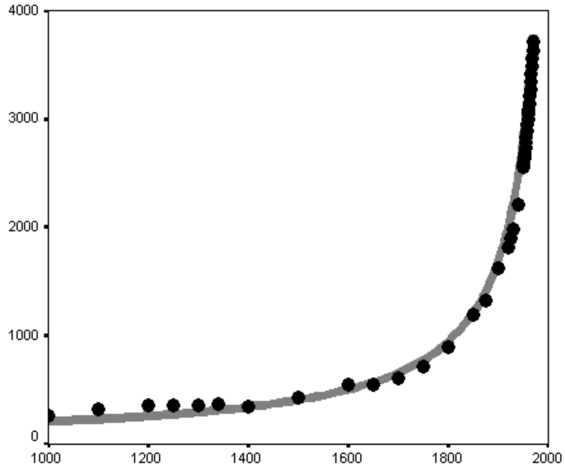
[6] Thomlinson 1975; McEvedy and Jones 1978; Biraben 1980; Modelski 2003; UN Population Division 2006; U.S. Bureau of the Census 2006.

[7] Thomlinson 1975; McEvedy and Jones 1978; Biraben 1980; Maddison 2001; Modelski 2003; U.S. Bureau of the Census 2006.

[8] 350 million (McEvedy and Jones 1978), 374 million (Biraben 1980).

equation and the most detailed series of empirical estimates looks as follows (see Diagram 0.3):

Diagram 0.3. Correlation between Empirical Estimates of World Population (in millions, 1000 – 1970) and the Curve Generated by von Foerster's Equation



NOTE: black markers correspond to empirical estimates of the world population by McEvedy and Jones (1978) for 1000–1950 and the U.S. Bureau of the Census (2006) for 1950–1970. The grey curve has been generated by von Foerster's equation (0.4).

The formal characteristics are as follows: $R = 0.998$; $R^2 = 0.996$; $p = 9.4 \times 10^{-17} \approx 1 \times 10^{-16}$. For readers unfamiliar with mathematical statistics: R^2 can be regarded as a measure of the fit between the dynamics generated by a mathematical model and the empirically observed situation, and can be interpreted as the proportion of the variation accounted for by the respective equation. Note that 0.996 also can be expressed as 99.6%.[9] Thus, von Foerster's equation accounts for an astonishing 99.6% of all the macrovariation in world population, from 1000 CE through 1970, as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census (2006).[10]

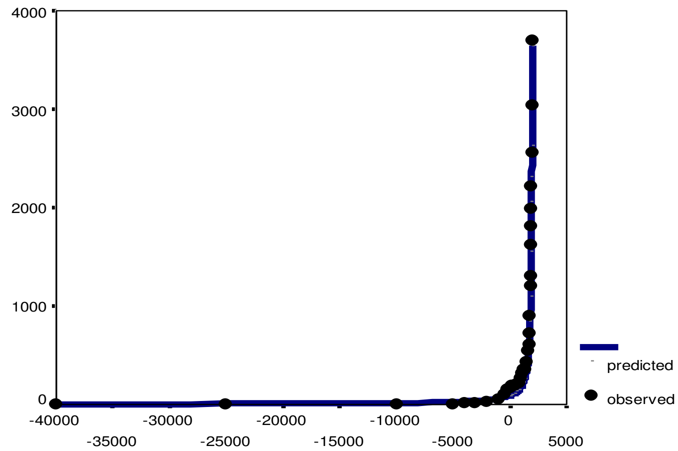
[9] The second characteristic (*p*, standing for "probability") is a measure of the correlation's statistical significance. A bit counterintuitively, the lower the value of *p*, the higher the statistical significance of the respective correlation. This is because *p* indicates the probability that the observed correlation could be accounted solely by chance. Thus, $p = 0.99$ indicates an extremely low statistical significance, as it means that there are 99 chances out of 100 that the observed correlation is the result of a coincidence, and, thus, we can be quite confident that there is no systematic relationship (at least, of the kind that we study) between the two respective variables. On the other hand, $p = 1 \times 10^{-16}$ indicates an extremely high statistical significance for the correlation, as it means that there is only one chance out of 10000000000000000 that the observed correlation is the result of pure coincidence (in fact, a correlation is usually considered as statistically significant with $p < 0.05$).

[10] In fact, with slightly different parameters ($C = 164890.45$; $t_0 = 2014$) the fit (R^2) between the dynamics generated by von Foerster's equation and the macrovariation of world population for CE 1000 – 1970 as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census

Note also that the empirical estimates of world population find themselves aligned in an extremely neat way along the hyperbolic curve, which convincingly justifies the designation of the pre-1970s world population growth pattern as "hyperbolic".

Von Foerster and his colleagues detected the hyperbolic pattern of world population growth for 1 CE –1958 CE; later it was shown that this pattern continued for a few years after 1958,[11] and also that it can be traced for many millennia BCE (Kapitza 1992, 1999; Kremer 1993).[12] Indeed, the McEvedy and Jones (1978) estimates for world population for the period 5000–500 BCE are described rather accurately by a hyperbolic equation (R^2 = 0.996); and this fit remains rather high for 40000 – 200 BCE (R^2 = 0.990) (see below Appendix 2). The overall shape of the world's population dynamics in 40000 BCE – 1970 CE also follows the hyperbolic pattern quite well (see Diagram 0.4):

Diagram 0.4. World Population Dynamics, 40000 BCE – 1970 CE (in millions): the fit between predictions of a hyperbolic model and the observed data



NOTE: R = 0.998, R^2 = 0.996, $p << 0.0001$. Black markers correspond to empirical estimates of the world population by McEvedy and Jones (1978) and Kremer (1993) for 1000–1950, as well as

(2006) reaches 0.9992 (99.92%), whereas for 500 BCE – 1970 CE this fit increases to 0.9993 (99.93%) (with the following parameters: C = 171042.78; t_0 = 2016).

[11] Note that after the 1960s, world population deviated from the hyperbolic pattern more and more; at present it definitely is no longer hyperbolic (see, *e.g.*, Korotayev, Malkov, and Khaltourina 2006a: Chapter 1).

[12] In fact, Kremer asserts the presence of this pattern since 1 million BCE; Kapitza, since 4 million BCE! We, however, are not prepared to accept these claims, because it is far from clear even who constituted the "world population" in, say, 1 million BCE, let alone how their number could have been empirically estimated.

the U.S. Bureau of the Census (2006) data for 1950–1970. The solid line has been generated by the following version of von Foerster's equation:

$$N_t = \frac{189648.7}{2022-t}.$$

A usual objection (*e.g.*, Shishkov 2005) against the statement that the overall pattern of world population growth until the 1970s was hyperbolic is as follows. Since we simply do not know the exact population of the world for most of human history (and especially, before CE), we do not have enough information to detect the general shape of the world population dynamics through most of human history. Thus, there are insufficient grounds to accept the statement that the overall shape of the world population dynamics in 40000 BCE – 1970 CE was hyperbolic.

At first glance this objection looks very convincing. For example, for 1 BCE the world population estimates range from 170 million (McEvedy and Jones 1978) to 330 million (Durand 1977), whereas for 10000 BCE the estimate range becomes even more dramatic: 1–10 million (Thomlinson 1975). Indeed, it seems evident that with such uncertain empirical data, we are simply unable to identify the long-term trend of world population macrodynamics.

However, notwithstanding the apparent persuasiveness of this objection, we cannot accept it. Let us demonstrate why.

Let us start with 10000 CE. As was mentioned above, we have only a rather vague idea about how many people lived on the Earth that time. However, we can be reasonably confident that it was more than 1 million, and less than 10 million. Note that this is not even a guesstimate. Indeed, we know which parts of the world were populated by that time (most of it, in fact), what kind of subsistence economies were practiced[13] (see, *e.g.*, Peregrine and Ember 2001), and what the maximum number of people 100 square kilometers could support with any of these subsistence economies (see, *e.g.*, Korotayev 1991). Thus, we know that with foraging technologies practiced by human populations in 10000 BCE, the Earth could not have supported more than 10 million people (and the actual world population is very likely to have been substantially smaller). Regarding world population in 40000 BCE, we can be sure only that it was somewhat smaller than in 10000 BCE. We do not know what exactly the difference was, but as we shall see below, this is not important for us in the context of this discussion.

The available estimates of world population between 10000 BCE and 1 CE can, of course, be regarded as educated guesstimates. However, in 2 CE the situation changes substantially, because this is the year of the "earliest preserved census in the world" (Bielenstein 1987: 14). Note also that this census was performed in China, one of the countries that is most important for us in this con-

[13] Note that at that time these economies were exclusively foraging (though quite intensive in a few areas of the world [see, *e.g.*, Grinin 2003b]).

text. This census recorded 59 million taxable inhabitants of China (*e.g.*, Bielenstein 1947: 126, 1986: 240; Durand 1960: 216; Loewe 1986: 206), or 57.671 million according to a later re-evaluation by Bielenstein (1987: 14).[14] Up to the 18th century the Chinese counts tended to underestimate the population, since before this they were not real census, but rather registrations for taxation purposes; in any country a large number of people would do their best to escape such a registration in order to avoid paying taxes, and it is quite clear that some part of the Chinese population normally succeeded in this (see, *e.g.*, Durand 1960). Hence, at least we can be confident that in 2 CE the world population was no less than 57.671 million. It is also quite clear that the world population was substantially more than that. For this time we also have data from a census of the Roman citizenry (for 14 CE), which, together with information on Roman social structure and data from narrative and archaeological sources, makes it possible to identify with a rather high degree of confidence the order of magnitude of the population of the Roman Empire (with available estimates in the range of 45–80 million [Durand 1977: 274]). Textual sources and archaeological data also make it possible to identify the order of magnitude of the population of the Parthian Empire (10–20 million), and of India (50–100 million) (Durand 1977). Data on the population for other regions warrant less confidence, but it is still quite clear that their total population was much smaller than that of the four above-mentioned regions (which in 2 CE comprised most of the world population). Archaeological evidence suggests that population density for the rest of the world would have been considerably lower than in the "Four Regions" themselves. In general, then, we can be quite sure that the world population in 2 CE could scarcely have been less than 150 million; it is very unlikely that it was more than 350 million.

Let us move now to 1800 CE. For this time we have much better population data than ever before for most of Europe, the United States, China[15], Egypt[16], India, Japan, and so on (Durand 1977). Hence, for this year we can be quite confident that world population could scarcely have been less than 850 million and more than 1 billion. The situation with population statistics further improves by 1900[17] for which time there is not much doubt that world population this year was within the range of 1600–1750 million. Finally, by 1960 population statistics had improved dramatically, and we can be quite confident that world population then was within the range of 2900–3100 million.

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[14] Or 57.671 million according to a later re-evaluation by Bielenstein (1987: 14).

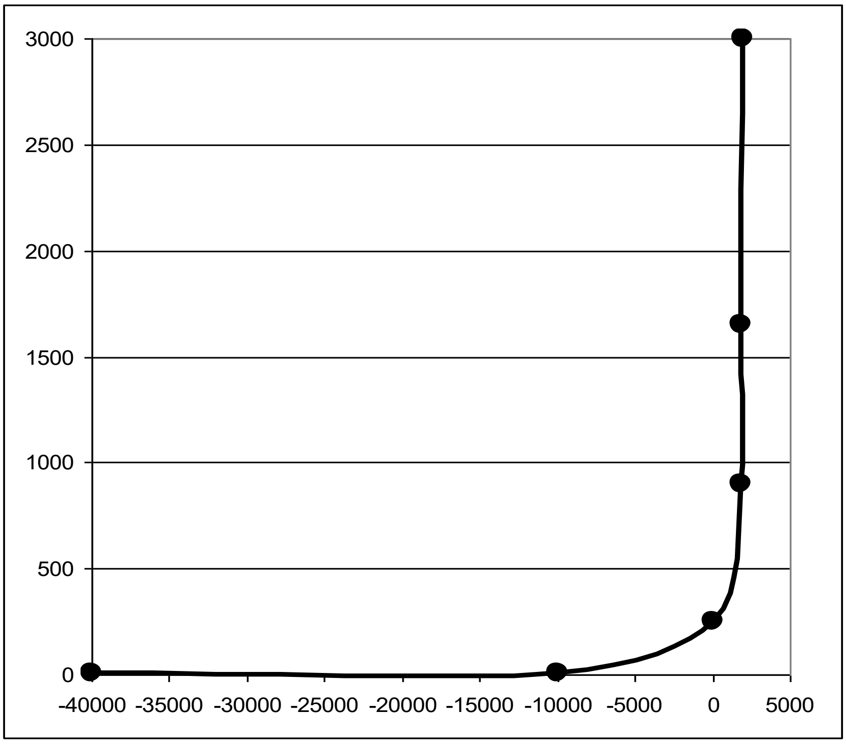
[15] Due to the separation of the census registration from the tax assessment conducted in the first half of the 18th century, the Chinese population in 1800 had no substantive reason for avoiding the census registration. Therefore, the Chinese census data for this time are particularly reliable (*e.g.*, Durand 1960: 238; see also Chapter 2 of this book).

[16] Due to the first scientific estimation of the Egyptian population performed by the members of the scientific mission that accompanied Napoleon to Egypt (Jomard 1818).

[17] With a notable exception of China (Durand 1960; see also below Chapter 2).

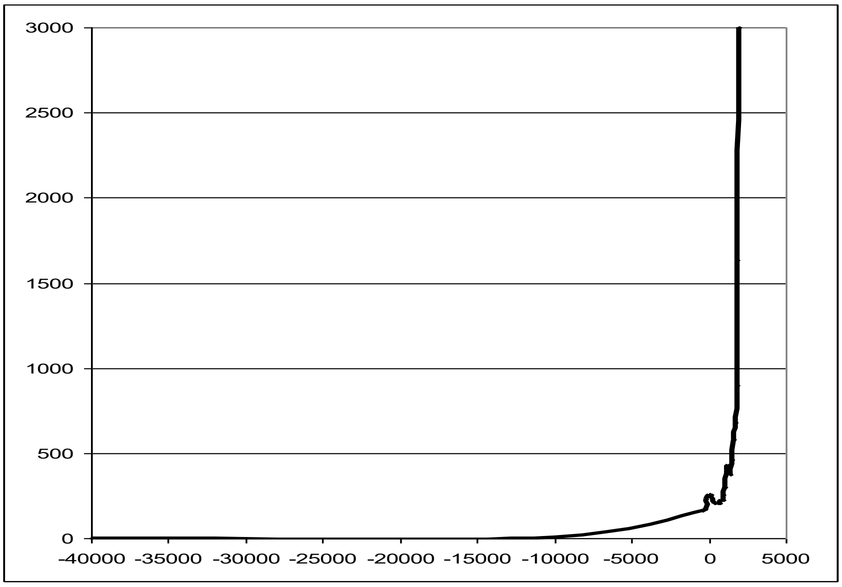
Now let us plot the mid points of the above mentioned estimate ranges and connect the respective points. We will get the following picture (see Diagram 0.5):

Diagram 0.5



As we see the resulting pattern of world population dynamics has an unmistakably hyperbolic shape. Now you can experiment and move any points within the estimate ranges as much as you like. You will see that the overall hyperbolic shape of the long-term world population dynamics will remain intact. What is more, you can fill the space between the points with any estimates you find. You will see that the overall shape of the world population dynamics will always remain distinctly hyperbolic. Replace, for example, the estimates of McEvedy and Jones (1978) used by us earlier for Diagram 0.4 in the range between 10000 BCE and 1900 CE with the ones of Biraben (1980) (note that generally Biraben's estimates are situated in the opposite side of the estimate range in relation to the ones of McEvedy and Jones). You will get the following picture (see Diagram 0.6):

Diagram 0.6



As we see, the overall shape of the world population dynamics remains unmistakably hyperbolic.

So what is the explanation for this apparent paradox? Why, though world population estimates are evidently infirm for most of human history, can we be sure that long-term world population dynamics pattern was hyperbolic?

The answer is simple, for in the period in question the world population grew by orders of magnitude. It is true that for most part of human history we cannot be at all confident of the exact value within a given order of magnitude. But with respect to any time-point within any period in question, we can be already perfectly confident about the order of magnitude of the world population. Hence, it is clear that whatever discoveries are made in the future, whatever re-evaluations are performed, the probability that they will show that the overall world population growth pattern in 40000 BCE – 1970 CE was not hyperbolic (but, say, exponential or lineal) is very close to zero indeed.

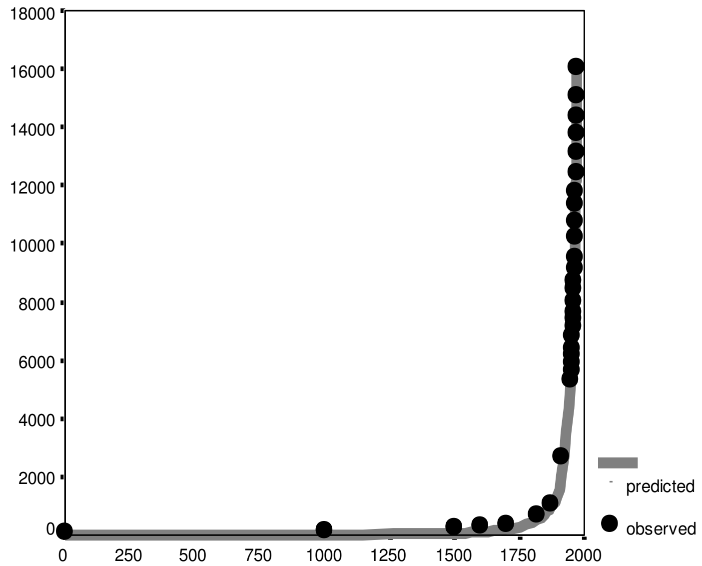
Note that if von Foerster, Mora, and Amiot also had at their disposal, in addition to world population data, data on the world GDP dynamics for 1–1973 (published, however, only in 2001 by Maddison [Maddison 2001]), they could have made another striking "prediction" – that on Saturday, 23 July, A.D. 2005 an "economic doomsday" would take place; that is, on that day the world GDP would become infinite if the economic growth trend observed in 1–1973 CE continued. They also would have found that in 1–1973 CE the world GDP growth followed a quadratic-hyperbolic rather than simple hyperbolic pattern.

Indeed, Maddison's estimates of the world GDP dynamics for 1–1973 CE are almost perfectly approximated by the following equation:

$$G_t = \frac{C}{(t_0 - t)^2}, \tag{0.5}$$

where G_t is the world GDP (in billions of 1990 international dollars, in purchasing power parity [PPP]) in year t, C = 17355487.3 and t_0 = 2005.56 (see Diagram 0.7):

Diagram 0.7. World GDP Dynamics, 1–1973 CE (in billions of 1990 international dollars, PPP): the fit between predictions of a quadratic-hyperbolic model and the observed data



NOTE: R = .9993, R^2 = .9986, p << .0001. The black markers correspond to Maddison's (2001) estimates (Maddison's estimates of the world per capita GDP for 1000 CE has been corrected on the basis of Meliantsev [1996, 2003, 2004a, 2004b]). The grey solid line has been generated by the following equation:

$$G = \frac{17749573.1}{(2006 - t)^2}.$$

Actually, as was mentioned above, the best fit is achieved with C = 17355487.3 and t_0 = 2005.56 (which gives just the "doomsday Saturday, 23 July, 2005"), but we have decided to keep hereafter to integer numbered years.

The only difference between the simple and quadratic hyperbolas is that the simple hyperbola is described mathematically with equation (0.2):

$$y = \frac{k}{x}, \qquad (0.2)$$

whereas the quadratic hyperbolic equation has x^2 instead of just x:

$$y = \frac{k}{x^2}. \qquad (0.6)$$

Of course, this equation can also be written as follows:

$$y = \frac{k}{(x_0 - x)^2}. \qquad (0.7)$$

It is this equation that was used above to describe the world economic dynamics between 1 and 1973 CE. The algorithm for calculating the world GDP still remains very simple. *E.g.*, to calculate the world GDP in 1905 (in billions of 1990 international dollars, PPP), one should first subtract 1905 from 2005, but than to divide C (17355487.3) not by the resultant difference (100), but by its square (100^2 = 10000).

Those readers who are not familiar with mathematical models of population hyperbolic growth should have a lot of questions at this point.[18] How could the long-term macrodynamics of the most complex social system be described so accurately with such simple equations? Why do these equations look so strange? Why, indeed, can we estimate the world population in year x so accurately just by subtracting x from the "Doomsday" year and dividing some constant with the resultant difference? And why, if we want to know the world GDP in this year, should we square the difference prior to dividing? Why was the hyperbolic growth of the world population accompanied by the quadratic hyperbolic growth of the world GDP? Is this a coincidence? Or are the hyperbolic growth of the world population and the quadratic hyperbolic growth of the world GDP just two sides of one coin, two logically connected aspects of the same process?

In the first part of our *Introduction to Social Macrodynamics* we have tried to provide answers to this question and these answers are summarized below.

[18] Whereas the answers to the questions regarding the quadratic hyperbolic growth of the world GDP might not have been quite clear even for those readers who know the hyperbolic demographic models.

However, before starting this we would like to state that our experience shows that most readers who are not familiar with mathematics stop reading books (at least our books) as soon as they come across the words – "differential equation". Thus, we have to ask such readers not to get scared with the presence of these words in the next passage and to move further. You will see that it is not as difficult to understand differential equations (or, at least, some of those equations), as one might think.

To start with, the von Foerster equation, $N_t = \frac{C}{t_0 - t}$, is just the solution for the following differential equation (see, *e.g.*, Korotayev, Malkov, and Khaltourina 2006a: 119–20):

$$\frac{dN}{dt} = \frac{N^2}{C}. \quad (0.8)$$

This equation can be also written as:

$$\frac{dN}{dt} = aN^2, \quad (0.9)$$

where $a = \frac{1}{C}$.

What is the meaning of this mathematical expression, $\frac{dN}{dt} = aN^2$? In our context *dN/dt* denotes the absolute population growth rate at some moment of time. Hence, this equation states that the absolute population growth rate at any moment of time should be proportional to the square of population at this moment.

Note that by dividing both parts of equation (0.9) with *N* we will get the following:

$$\frac{dN}{dt} : N = aN, \quad (0.10)$$

Further, note that $\frac{dN}{dt} : N$ is just a designation of the relative population growth rate. Indeed, as we remember, *dN/dt* is the absolute population growth rate at a certain moment of time. Imagine that at this moment the population (*N*) is 100 million and the absolute population growth rate (*dN*/*dt*) is 1 million a year. If we divide now (*dN*/*dt* = 1 million) by (*N* = 100 million) we will get 0.01, or 1%; which would mean that the relative population growth rate at this moment is 1% a year.

If we denote relative population growth rate as r_N, we will get a particularly simple version of the hyperbolic equation:

$$r_N = aN\ . \tag{0.10'}$$

Thus, with hyperbolic growth the relative population growth rate (r_N) is linearly proportional to the population size (*N*). Note that this significantly demystifies the problem of the world population hyperbolic growth. Now to explain this hyperbolic growth we should just explain why for many millennia the world population's absolute growth rate tended to be proportional to the square of the population.

We believe that the most significant progress towards the development of a compact mathematical model providing a convincing answer to this question has been achieved by Michael Kremer (1993), whose model will be summarized next.

Kremer's model is based on the following assumptions:

1) First of all he makes "the Malthusian (1978) assumption that population is limited by the available technology, so that the growth rate of population is proportional to the growth rate of technology" (Kremer 1993: 681–2).[19] This statement looks quite convincing. Indeed, throughout most of human history the world population was limited by the technologically determined ceiling of the carrying capacity of land. As was mentioned above, with foraging subsistence technologies the Earth could not support more than 10 million people, because the amount of naturally available useful biomass on this planet is limited, and the world population could only grow over this limit when the people started to apply various means to artificially increase the amount of available biomass, that is with the transition from foraging to food production. However, the extensive agriculture also can only support a limited number of people, and further growth of the world population only became possible with the intensification of agriculture and other technological improvements.

This assumption is modeled by Kremer in the following way. Kremer assumes that overall output produced by the world economy equals

$$G = rTN^{\alpha}\ , \tag{0.11}$$

where *G* is output, *T* is the level of technology, *N* is population, $0 < \alpha < 1$ and *r* are parameters.[20] With constant *T* (that is, without any technological growth)

[19] In addition to this, the absolute growth rate is proportional to the population itself – with a given relative growth rate a larger population will increase more in absolute numbers than a smaller one.

[20] Kremer uses the following symbols to denote respective variables: *Y* – output, *p* – population, *A* – the level of technology, *etc.*; while describing Kremer's models we will employ the symbols (closer to the Kapitza's [1992, 1999]) used in our model, naturally without distorting the sense of Kremer's equations.

this equation generates Malthusian dynamics. For example, let us assume that $\alpha = 0.5$, and that T is constant. Let us recollect that $N^{0.5}$ is just $\sqrt{N}$. Thus, a four time expansion of the population will lead to a twofold increase in output (as $\sqrt{4} = 2$). In fact, here Kremer models Ricardo's law of diminishing returns to labor (1817), which in the absence of technological growth produces just Malthusian dynamics. Indeed, if the population grows 4 times, and the output grows only twice, this will naturally lead to a twofold decrease of per capita output. How could this affect population dynamics?

Kremer assumes that "population increases above some steady state equilibrium level of per capita income, *m*, and decreases below it" (Kremer 1993: 685). Hence, with the decline of per capita income, the population growth will slow down and will become close to zero when the per capita income approaches *m*. Note that such a dynamics was actually rather typical for agrarian societies, and its mechanisms are known very well – indeed, if per capita incomes decline closely to *m*, it means the decline of nutrition and health status of most population, which will lead to an increase in mortality and a slow down of population growth (see, *e.g.*, Malthus 1978 [1798]; Postan 1950, 1972; Abel 1974, 1980; Cameron 1989; Artzrouni and Komlos 1985; Komlos and Nefedov 2002; Turchin 2003; Nefedov 2004 and Chapters 1–3 below). Thus, with constant technology, population will not be able to exceed the level at which per capita income ($g = G/N$) becomes equal to *m*. This implies that for any given level of technological development (T) there is "a unique level of population, *n*ॐ," that cannot be exceeded with the given level of technology (Kremer 1993: 685). Note that *n*ॐ can be also interpreted as the Earth carrying capacity, that is, the maximum number of people that the Earth can support with the given level of technology.

However, as is well known, the technological level is not a constant, but a variable. And in order to describe its dynamics Kremer employs his second basic assumption:

2) "High population spurs technological change because it increases the number of potential inventors…[21] In a larger population there will be proportionally more people lucky or smart enough to come up with new ideas" (Kremer 1993: 685), thus, "the growth rate of technology is proportional to total population".[22] In fact, here Kremer uses the main assumption of the Endogenous Technological Growth theory (Kuznets 1960; Grossman and Helpman 1991; Aghion and Howitt 1992, 1998; Simon 1977, 1981, 2000; Komlos and Nefedov

[21] "This implication flows naturally from the nonrivalry of technology… The cost of inventing a new technology is independent of the number of people who use it. Thus, holding constant the share of resources devoted to research, an increase in population leads to an increase in technological change" (Kremer 1993: 681).

[22] Note that "the growth rate of technology" means here the relative growth rate (*i.e.*, the level to which technology will grow in a given unit of time in proportion to the level observed at the beginning of this period).

2002; Jones 1995, 2003, 2005 *etc.*). As this supposition, to our knowledge, was first proposed by Simon Kuznets (1960), we shall denote the corresponding type of dynamics as "Kuznetsian",[23] while the systems in which the "Kuznetsian" population-technological dynamics is combined with the "Malthusian" demographic one will be denoted as "Malthusian-Kuznetsian". In general, we find this assumption rather plausible – in fact, it is quite probable that, other things being equal, within a given period of time, one billion people will make approximately one thousand times more inventions than one million people.

This assumption is expressed by Kremer mathematically in the following way:

$$\frac{dT}{dt} = bNT \quad . \tag{0.12}$$

Actually, this equation says just that the absolute technological growth rate at a given moment of time is proportional to the technological level observed at this moment (the wider is the technological base, the more inventions could be made on its basis), and, on the other hand, it is proportional to the population (the larger the population, the higher the number of potential inventors).[24]

In his basic model Kremer assumes "that population adjusts instantaneously to *n*ॐ" (1993: 685); he further combines technology and population determination equations and demonstrates that their interaction produces just the hyperbolic population growth (Kremer 1993: 685–6; see also Podlazov 2000, 2001, 2002, 2004; Tsirel 2004; Korotayev, Malkov, and Khaltourina 2006a: 21–36).

Kremer's model provides a rather convincing explanation of *why* throughout most of human history the world population followed the hyperbolic pattern with the absolute population growth rate tending to be proportional to N^2. For example, why will the growth of population from, say, 10 million to 100 million, result in the growth of *dN/dt* 100 times? Kremer's model explains this rather convincingly (though Kremer himself does not appear to have spelled this out in a sufficiently clear way). The point is that the growth of world population from 10 to 100 million implies that human technology also grew approximately 10 times (given that it will have proven, after all, to be able to support a ten times larger population). On the other hand, the growth of a population 10 times also implies a 10-fold growth of the number of potential inventors, and, hence, a 10-fold increase in the relative technological growth rate. Hence, the absolute technological growth rate will grow 10 × 10 = 100 times (as, in accordance with equation (0.12), an order of magnitude higher number of people having at their disposal an order of magnitude wider technological basis would tend to make

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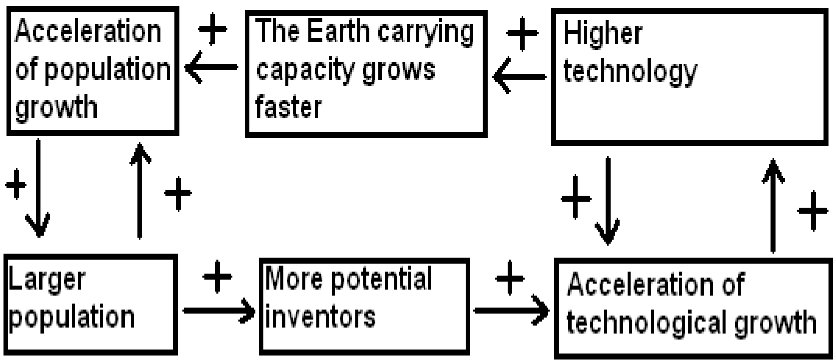
[23] In Economic Anthropology it is usually denoted as "Boserupian" (see, *e.g.*, Boserup 1965; Lee 1986).

[24] Kremer did not test this hypothesis empirically in a direct way. Note, however, that our own empirical test of this hypothesis has supported it (see below Appendix 1).

two orders of magnitude more inventions). And as *N* tends to the technologically determined carrying capacity ceiling, we have good reason to expect that *dN/dt* will also grow just by about 100 times.

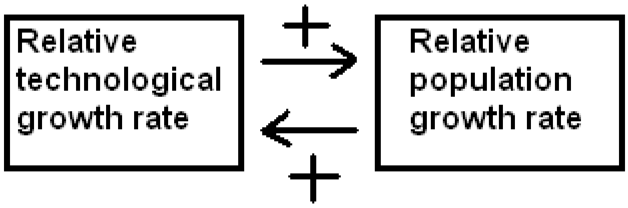
In fact, Kremer's model suggests that the hyperbolic pattern of the world's population growth could be accounted for by the nonlinear second order positive feedback mechanism that was shown long ago to generate just the hyperbolic growth, known also as the "blow-up regime" (see, *e.g.*, Kurdjumov 1999; Knjazeva and Kurdjumov 2005). In our case this nonlinear second order positive feedback looks as follows: the more people – the more potential inventors – the faster technological growth – the faster growth of the Earth's carrying capacity – the faster population growth – with more people you also have more potential inventors – hence, faster technological growth, and so on (see Diagram 0.8):

Diagram 0.8. Block Scheme of the Nonlinear Second Order Positive Feedback between Technological Development and Demographic Growth (version 1)



In fact, this positive feedback can be graphed even more succinctly (see Diagram 0.9a):

Diagram 0.9a. Block Scheme of the Nonlinear Second Order Positive Feedback between Technological Development and Demographic Growth (version 2)



Note that the relationship between technological development and demographic growth cannot be analyzed through any simple cause-and-effect model, as we observe a true dynamic relationship between these two processes – each of them is both the cause and the effect of the other.

It is remarkable that Kremer's model suggests ways to answer one of the main objections raised against the hyperbolic models of the world's population growth. Indeed, at present the mathematical models of world population growth as hyperbolic have not been accepted by the academic social science community [The title of the most recent article by a social scientist discussing Kapitza's model, "Demographic Adventures of a Physicist" (Shishkov 2005), is rather telling in this respect]. We believe that there are substantial reasons for such a position, and that the authors of the respective models are as much to blame for this rejection as are social scientists.

Indeed, all these models are based on an assumption that world population can be treated as having been an integrated system for many centuries, if not millennia, before 1492. Already in 1960, von Foerster, Mora, and Amiot spelled out this assumption in a rather explicit way:

"However, what may be true for elements which, because of lack of adequate communication among each other, have to resort to a competitive, (almost) zero-sum multiperson game may be false for elements that possess a system of communication which enables them to form coalitions until all elements are so strongly linked that the population as a whole can be considered from a game-theoretical point of view as a single person playing a two-person game with nature as its opponent" (von Foerster, Mora, and Amiot 1960: 1292).

However, did, *e.g.*, in 1–1500 CE, the inhabitants of, say, Central Asia, Tasmania, Hawaii, Terra del Fuego, the Kalahari *etc.* (that is, just the world population) really have "adequate communication" to make "all elements… so strongly linked that the population as a whole can be considered from a game-theoretical point of view as a single person playing a two-person game with nature as its opponent"? For any historically minded social scientist the answer to this question is perfectly clear and, of course, it is squarely negative. Against this background it is hardly surprising that those social scientists who have happened to come across hyperbolic models for world population growth have tended to treat them merely as "demographic adventures of physicists" (note that indeed, nine out of eleven currently known authors of such models are physicists); none of the respective authors (von Foerster, Mora, and Amiot 1960; von Hoerner 1975; Kapitza 1992, 1999; Kremer 1993; Cohen 1995; Podlazov 2000, 2001, 2002, 2004; Johansen and Sornette 2001; Tsirel 2004), after all, has provided any convincing answer to the question above.

However, it is not so difficult to provide such an answer.

The hyperbolic trend observed for the world population growth after 10000 BCE does appear to be primarily a product of the growth of quite a real system, a system that seems to have originated in West Asia around that time in direct connection with the Neolithic Revolution. With Andre Gunder Frank (1990, 1993; Frank and Gills 1994), we denote this system as "the World System" (see also, *e.g.*, Modelski 2000, 2003; Devezas and Modelski 2003). The presence of the hyperbolic trend itself indicates that the major part of the entity in question had some systemic unity, and the evidence for this unity is readily available. Indeed, we have evidence for the systematic spread of major innovations (domesticated cereals, cattle, sheep, goats, horses, plow, wheel, copper, bronze, and later iron technology, and so on) throughout the whole North African – Eurasian Oikumene for a few millennia BCE (see, *e.g.*, Chubarov 1991, or Diamond 1999 for a synthesis of such evidence). As a result, the evolution of societies of this part of the world already at this time cannot be regarded as truly independent. By the end of the 1st millennium BCE we observe a belt of cultures, stretching from the Atlantic to the Pacific, with an astonishingly similar level of cultural complexity characterized by agricultural production of wheat and other specific cereals, the breeding of cattle, sheep, and goats; use of the plow, iron metallurgy, and wheeled transport; development of professional armies and cavalries deploying rather similar weapons; elaborate bureaucracies, and Axial Age ideologies, and so on – this list could be extended for pages). A few millennia before, we would find another belt of societies strikingly similar in level and character of cultural complexity, stretching from the Balkans up to the Indus Valley outskirts (Peregrine and Ember 2001: vols. 4 and 8; Peregrine 2003). Note that in both cases, the respective entities included the major part of the contemporary world's population (see, *e.g.* McEvedy and Jones 1978; Durand 1977 *etc.*). We would interpret this as a tangible result of the World System's functioning. The alternative explanations would involve a sort of miraculous scenario – that these cultures with strikingly similar levels and character of complexity somehow developed independently of one another in a very large but continuous zone, while for some reason nothing comparable to them appeared elsewhere in the other parts of the world, which were not parts of the World System. We find such an alternative explanation highly implausible.

Thus, we would tend to treat the world population's hyperbolic growth pattern as reflecting the growth of quite a real entity, the World System.

A few other points seem to be relevant here. Of course there would be no grounds for speaking about a World System stretching from the Atlantic to the Pacific, even at the beginning of the 1st millennium CE, if we applied the "bulk-good" criterion suggested by Wallerstein (1974, 1987, 2004), as there was no movement of bulk goods at all between, say, China and Europe at this time (as we have no reason to disagree with Wallerstein in his classification of the 1st century Chinese silk reaching Europe as a luxury rather than a bulk good). However, the 1st century CE (and even the 1st millennium BCE) World System definitely qualifies as such if we apply the "softer" information-network criterion suggested by Chase-Dunn and Hall (1997). Note that at our level of analysis the presence of an information network covering the whole World System is a perfectly sufficient condition, which makes it possible to consider this system as a single evolving entity. Yes, in the 1st millennium BCE any bulk goods could hardly penetrate from the Pacific coast of Eurasia to its Atlantic coast. However, the World System had reached by that time such a level of integration that iron metallurgy could spread through the whole of the World System within a few centuries.

Yes, in the millennia preceding the European colonization of Tasmania its population dynamics – oscillating around the 4000 level (*e.g.*, Diamond 1999) – were not influenced by World System population dynamics and did not influence it at all. However, such facts just suggest that since the 10th millennium BCE the dynamics of the world population reflect very closely just the dynamics of the World System population.

On the basis of Kremer's model we (Korotayev, Malkov, and Khaltourina 2006a: 34–66) have developed a mathematical model that describes not only the hyperbolic world population growth, but also the macrodynamics of the world GDP production up to 1973:

$$G = k_1 T N^{\alpha}, \tag{0.11}$$

$$\frac{dN}{dt} = k_2 S N, \tag{0.13}$$

$$\frac{dT}{dt} = k_3 N T, \tag{0.12}$$

where G is the world GDP, T is the World System technological level, N is population, and S is the surplus produced, per person, over the amount (m) minimally necessary to reproduce the population with a zero growth rate in a Malthusian system (thus, $S = g - m$, where g denotes per capita GDP); k_1, k_2, k_3, and α ($0 < \alpha < 1$) are parameters.

We have also shown (Korotayev, Malkov, and Khaltourina 2006a: 34–66) that this model can be further simplified to the following form:

$$\frac{dN}{dt} = aSN \,, \tag{0.13}$$

$$\frac{dS}{dt} = bNS \,, \tag{0.14}$$

while the world GDP (*G*) can be calculated using the following equation:

$$G = mN + SN \,. \tag{0.15}$$

Note that the mathematical analysis of the basic model (0.11)-(0.13)-(0.12) suggests that during the "Malthusian-Kuznetsian" macroperiod of human history (that is, up to the 1960s) the amount of *S* (per capita surplus produced at the given level of World System development) should be proportional, in the long run, to the World System's population: *S* = *kN*. Our statistical analysis of available empirical data has confirmed this theoretical proportionality (Korotayev, Malkov, and Khaltourina 2006a: 49–50). Thus, in the right-hand side of equation (0.13) *S* can be replaced with *kN*, and as a result we arrive at the following equation:

$$\frac{dN}{dt} = kaN^2 \qquad (0.9)$$ [25]

As we remember, the solution of this type of differential equations is

$$N_t = \frac{C}{(t_0 - t)} \,, \tag{0.1}$$

and this produces simply a hyperbolic curve.

As, according to our model, *S* can be approximated as *kN*, its long-term dynamics can be approximated with the following equation:

$$S = \frac{kC}{t_0 - t} \,. \tag{0.16}$$

Thus, the long-term dynamics of the most dynamic component of the world GDP, *SN*, "the world surplus product ", can be approximated as follows:

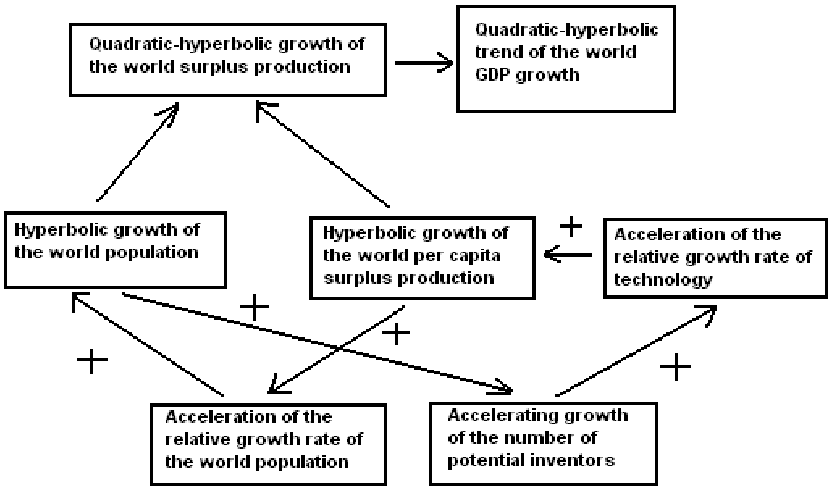
$$SN = \frac{kC^2}{(t_0 - t)^2} \,. \tag{0.17}$$

[25] Thus we arrive, on a theoretical basis, at the differential equation discovered empirically by von Hoerner (1975) and Kapitza (1992, 1999).

Of course, this suggests that the long-term world GDP dynamics up to the early 1970s must be approximated better by a quadratic hyperbola than by a simple one; and, as we could see above (see Diagram 0.7), this approximation works very effectively indeed.

Thus, up to the 1970s the hyperbolic growth of the world population was accompanied by the quadratic-hyperbolic growth of the world GDP, just as is suggested by our model. Note that the hyperbolic growth of the world population and the quadratic hyperbolic growth of the world GDP are very tightly connected processes, actually two sides of the same coin, two dimensions of one process propelled by the nonlinear second order positive feedback loops between the technological development and demographic growth (see Diagram 0.9b):

Diagram 0.9b. Block Scheme of the Nonlinear Second Order Positive Feedback between Technological Development and Demographic Growth (version 3)



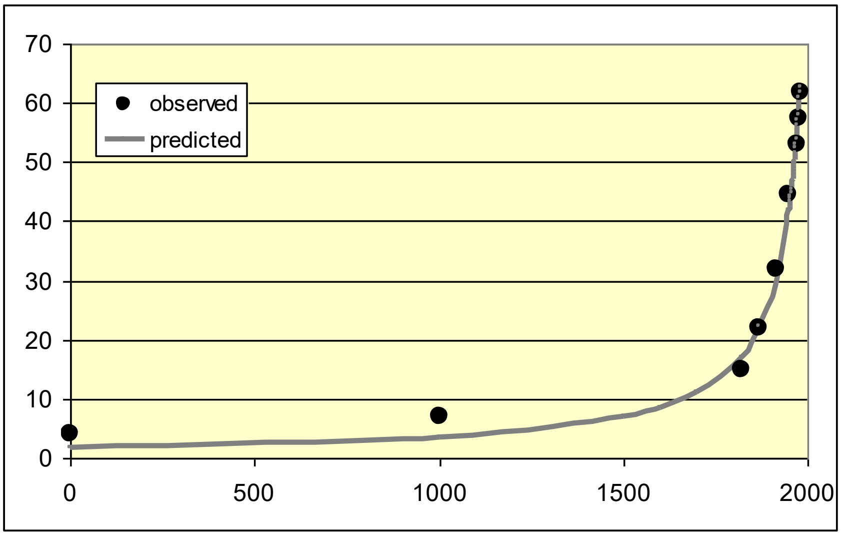
We have also demonstrated (Korotayev, Malkov, and Khaltourina 2006a: 67–80) that the World System population's literacy (l) dynamics are rather accurately described by the following differential equation:

$$\frac{dl}{dt} = aSl(1-l)\ , \qquad (0.18)$$

where l is the proportion of the population that is literate, S is per capita surplus, and a is a constant. In fact, this is a version of the autocatalytic model. It has the following sense: the literacy growth is proportional to the fraction of the population that is literate, l (potential teachers), to the fraction of the population that is illiterate, $(1 - l)$ (potential pupils), and to the amount of per capita surplus S, since it can be used to support educational programs (in addition to this, S reflects the technological level T that implies, among other things, the level of development of educational technologies). Note that, from a mathematical point of view, equation (0.18) can be regarded as logistic where saturation is reached at literacy level $l = 1$, and S is responsible for the speed with which this level is being approached.

It is important to stress that with low values of l (which would correspond to most of human history, with recent decades being the exception), the rate of increase in world literacy generated by this model (against the background of hyperbolic growth of S) can be approximated rather accurately as hyperbolic (see Diagram 0.10):

Diagram 0.10. World Literacy Dynamics, 1 – 1980 CE (%%): the fit between predictions of the hyperbolic model and the observed data



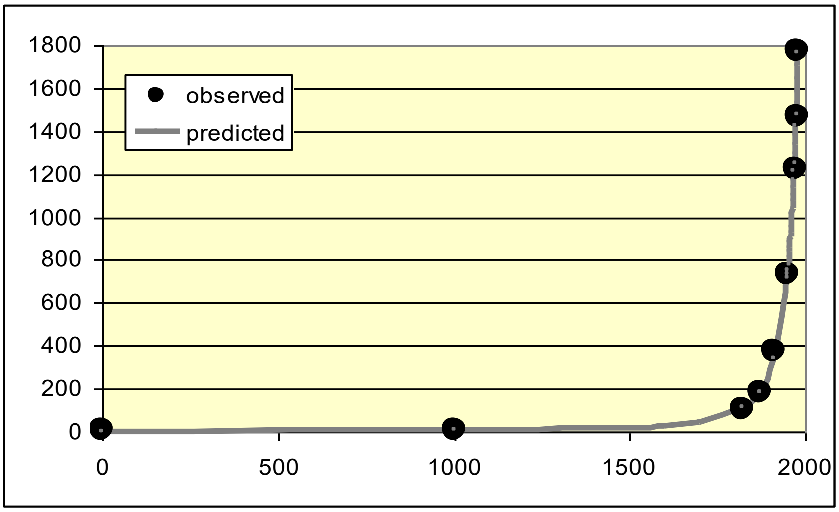
NOTE: $R = 0.997$, $R^2 = 0.994$, $p << 0.0001$. Black dots correspond to UNESCO/World Bank (2005) estimates for the period since 1970, and to Meliantsev's (1996, 2003, 2004a, 2004b) estimates for the earlier period. The grey solid line has been generated by the following equation:

$$l_t = \frac{3769.264}{(2040-t)^2} .$$

The best-fit values of parameters C (3769.264) and t_0 (2040) have been calculated with the least squares method.

The overall number of literate people is proportional both to the literacy level and to the overall population. As both of these variables experienced hyperbolic growth until the 1960s/1970s, one has sufficient grounds to expect that until recently the overall number of literate people in the world (L)[26] was growing not just hyperbolically, but rather in a quadratic-hyperbolic way (as was world GDP). Our empirical test has confirmed this – the quadratic-hyperbolic model describes the growth of the literate population of this planet with an extremely good fit indeed (see Diagram 0.11):

Diagram 0.11. World Literate Population Dynamics, 1 – 1980 CE (*L*, millions): the fit between predictions of the quadratic-hyperbolic model and the observed data



NOTE: R = 0.9997, R^2 = 0.9994, p << 0.0001. The black dots correspond to UNESCO/World Bank (2006) estimates for the period since 1970, and to Meliantsev's (1996, 2003, 2004a, 2004b) estimates for the earlier period; we have also taken into account the changes of age structure on the basis of UN Population Division (2006) data. The grey solid line has been generated by the following equation:

$$L_t = \frac{4958551}{(2033-t)^2}.$$

The best-fit values of parameters C (4958551) and t_0 (2033) have been calculated with the least squares method.

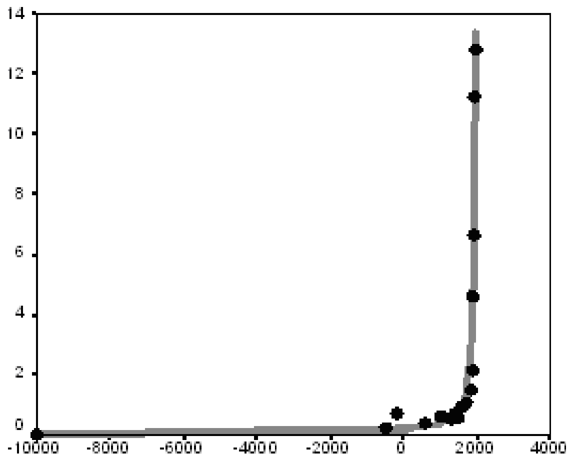
[26] Since literacy appeared, almost all of the Earth's literate population has lived within the World System; hence, the literate population of the Earth and the literate population of the World System have been almost perfectly synonymous.

Similar processes are observed with respect to world urbanization, the macrodynamics of which appear to be described by the differential equation:

$$\frac{du}{dt} = bSu(u_{\lim} - u) , \qquad (0.19)$$

where u is the proportion of the population that is urban, S is per capita surplus produced with the given level of the World System's technological development, b is a constant, and $u_{\lim}$ is the maximum possible proportion of the population that can be urban. Note that this model implies that during the "Malthusian-Kuznetsian" era of the blow-up regime, the hyperbolic growth of world urbanization must have been accompanied by a quadratic-hyperbolic growth of the urban population of the world, which is supported by our empirical tests (see Diagrams 0.12–13):

Diagram 0.12. World Megaurbanization Dynamics (% of the world population living in cities with > 250 thousand inhabitants), 10000 BCE – 1960 CE: the fit between predictions of the hyperbolic model and empirical estimates

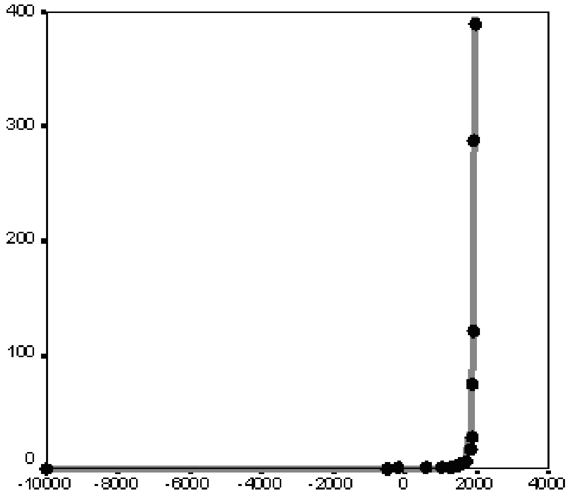


NOTE: R = 0.987, R^2 = 0.974, p << 0.0001. The black dots correspond to estimates of Chandler (1987), UN Population Division (2005), and White *et al.* (2006). The grey solid line has been generated by the following equation:

$$u_t = \frac{403.012}{(1990 - t)} .$$

The best-fit values of parameters C (403.012) and t_0 (1990) have been calculated with the least squares method. For a comparison, the best fit (R^2) obtained here for the exponential model is 0.492.

Diagram 0.13. Dynamics of World Urban Population Living in Cities with > 250000 Inhabitants (mlns.), 10000 BCE – 1960 CE: the fit between predictions of the quadratic-hyperbolic model and the observed data



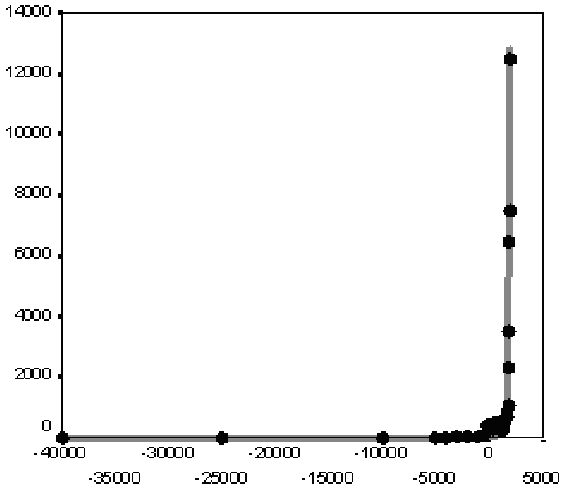
NOTE: R = 0.998, R^2 = 0.996, p << 0.0001. The black markers correspond to estimates of Chandler (1987), UN Population Division (2005), and White *et al.* (2006). The grey solid line has been generated by the following equation:

$$U_t = \frac{912057.9}{(2008-t)^2}.$$

The best-fit values of parameters C (912057.9) and t_0 (2008) have been calculated with the least squares method. For a comparison, the best fit (R^2) obtained here for the exponential model is 0.637.

Within this context it is hardly surprising to find that the general macrodynamics of the size of the largest settlement within the World System are also quadratic-hyperbolic (see Diagram 0.14):

Diagram 0.14. Dynamics of Size of the Largest Settlement of the World (thousands of inhabitants), 10000 BCE – 1950 CE: the fit between predictions of the quadratic-hyperbolic model and the observed data



NOTE: R = 0.992, R^2 = 0.984, p << 0.0001. The black markers correspond to estimates of Modelski (2003) and Chandler (1987). The grey solid line has been generated by the following equation:

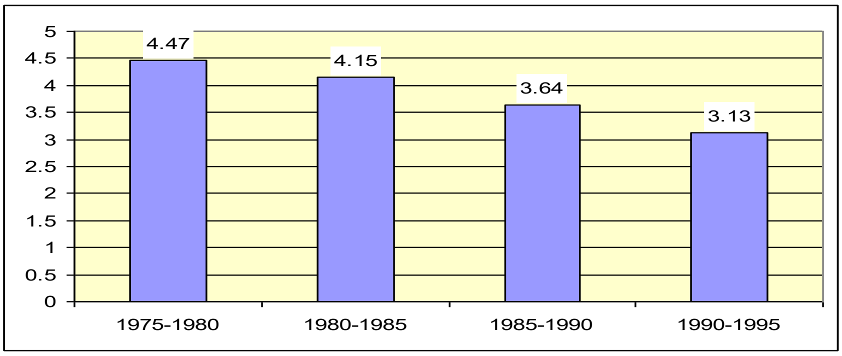
$$U_{\max t} = \frac{104020618573}{(2040-t)^2}.$$

The best-fit values of parameters C (104020618,5) and t_0 (2040) have been calculated with the least squares method. For a comparison, the best fit (R^2) obtained here for the exponential model is 0.747.

As has been demonstrated by cross-cultural anthropologists (see, *e.g.*, Naroll and Divale 1976; Levinson and Malone 1980: 34), for pre-agrarian, agrarian, and early industrial cultures the size of the largest settlement is a rather effective indicator of the general sociocultural complexity of a social system. This, of course, suggests that the World System's general sociocultural complexity also grew, in the "Malthusian-Kuznetsian" era, in a generally quadratic-hyperbolic way.

It is world literacy for which it is most evident that its hyperbolic growth could not continue, for any significant period, after the mid-1960s; after all, the literacy rate by definition cannot exceed 100 per cent just by definition. What is more, since the 1970s the saturation effect[27] described by our model started being felt more and more strongly and the rate of world literacy's growth began to slow (see Diagram 0.15):

Diagram 0.15. World Literacy Growth Dynamics, 1975 – 1995, the increase in percentage of adult literate population, by five-year periods



However, already before this, the hyperbolic growth of world literacy and of the other indicators of the human capital development had launched the process of diverging from the blow-up regime, signaling the end of the era of hyperbolic growth. As has been shown by us earlier (Korotayev, Malkov, and Khaltourina 2006a: 67–86), hyperbolic growth of population (as well as of cities, schools *etc.*) is only observed at relatively low (< 0.5, *i.e.*, < 50%) levels of world literacy. In order to describe the World System's demographic dynamics in the last decades (as well as in the near future), it has turned out to be necessary to extend the equation system (0.13)-(0.14) by adding to it equation (0.21), and by adding to equation (0.13) the multiplier $(1 - l)$, which results in equation (0.20), and produces a mathematical model that describes not only the hyperbolic de-

[27] On the ground, the saturation effect means, for example, that raising literacy from 98 to 100 per cent of the adult population would require much more time and effort than would raising it from 50 to 52 per cent.

velopment of the World System up to the 1960s/1970s, but also its withdrawal from the blow-up regime afterwards:

$$\frac{dN}{dt} = aSN(1-l) \ , \quad (0.20)$$

$$\frac{dS}{dt} = bNS \ , \quad (0.14)$$

$$\frac{dl}{dt} = cSl(1-l) \ . \quad (0.21)$$

We would like to stress that in no way are we claiming that the literacy growth is the only factor causing the demographic transition. Important roles were also played here by such factors as, for example, the development of medical care and social security subsystems. These variables, together with literacy, can be regarded as different parameters of one integrative variable, the human capital development index. These variables are connected with demographic dynamics in a way rather similar to the one described above for literacy. At the beginning of the demographic transition, the development of the social security subsystem correlates rather closely with the decline of mortality rates, as both are caused by essentially the same proximate factor – the GDP per capita growth. However, during the second phase, social security development produces quite a strong independent effect on fertility rates through the elimination of one of the main traditional incentives for the maximization of the number of children in the family.

The influence of the development of medical care on demographic dynamics shows even closer parallels with the effect produced by literacy growth. Note first of all that the development of modern medical care is connected in the most direct way with the development of the education subsystem. On the other hand, during the first phase of the demographic transition, the development of medical care acts as one of the most important factors in decreasing mortality. In the meantime, when the need to decrease fertility rates reaches critical levels, it is the medical care subsystem that develops more and more effective family planning technologies. It is remarkable that this need arises as a result of the decrease in mortality rates, which could not reach critically low levels without the medical care subsystem being sufficiently developed. Hence, when the need to decrease fertility rates reaches critical levels, those in need, almost by definition, find the medical care subsystem sufficiently developed to satisfy this need quite rapidly and effectively.

Let us recollect that the pattern of literacy's impact on demographic dynamics has an almost identical shape: the maximum values of population growth rates cannot be reached without a certain level of economic development, which cannot be achieved without literacy rates reaching substantial levels. Hence, again almost by definition, the fact that the system reached the maximum level of population growth rates implies that literacy – especially of females – had attained such a level that its negative impact on fertility rates would cause population growth rates to start to decline. On the other hand, the level of development of both medical care and social security subsystems displays a very strong correlation with literacy (see Korotayev, Malkov, and Khaltourina 2006a: Chapter 7). Thus, literacy rate turns out to be a very strong predictor of the development of both medical care and social security subsystems.

Note that in reality, as well as in our model, both the decline of mortality at the beginning of the demographic transition (which caused a demographic explosion) and the decline of fertility during its second phase (causing a dramatic decrease of population growth rates) were ultimately produced by essentially the same factor (human capital growth); there is therefore no need for us to include mortality and fertility as separate variables in our model. On the other hand, literacy has turned out to be a rather sensitive indicator of the development level of human capital, which has made it possible to avoid including its other parameters as separate variables in extended macromodels (for more detail see Korotayev, Malkov, and Khaltourina 2006a: Chapter 7).

Model (0.20)-(0.14)-(0.21) describes mathematically the divergence from the blow-up regime not only for world population and literacy dynamics, but also for world economic dynamics. However, this model does not describe the slowdown of the World System's economic growth observed after 1973. According to the model, the relative rate of world GDP growth should have continued to increase even after the World System began to diverge from the blow-up regime, though more and more slowly. In reality, however, after 1973 we observe not just a decline in the speed with which the world GDP rate grows – we observe a decline in the world GDP growth rate itself (see, *e.g.*, Maddison 2001). It appears that model (0.20)-(0.14)-(0.21) would describe the recent world economic dynamics if the $(1 - l)$ multiplier were added not only to its first equation, but also to the second (0.14). This multiplier might have the following sense: the literate population is more inclined to direct a larger share of its GDP to resource restoration and to prefer resource economizing strategies than is the illiterate one, which, on the one hand, paves the way toward a sustainable-development trajectory, but, on the other hand, slows down the economic growth rate (cp., *e.g.*, Liuri 2005).

Note that development, according to this scenario, does not invalidate Kremer's technological growth equation (0.12). Thus, the modified model does imply that the World System's divergence from the blow-up regime would stabilize the world population, the world GDP, and some other World-System development indicators (*e.g.*, urbanization and literacy as a result of saturation, *i.e.*, the achievement of the ultimate possible level); technological growth, however, will continue, though in exponential rather than hyperbolic form.

Due to the continuation of technological growth, the ending of growth in the world's GDP will not entail a cessation of growth in the standard of living of the world's population. A continuing rise in the world's standard of living is most likely to be achieved due to the so-called "Nordhaus effect" (Nordhaus 1997). The essence of this effect can be spelled out as follows: imagine that you are going to buy a new computer and plan to spend $1000 on this. Now imagine what computer you would have been able to buy with the same $1000 five years ago. Of course, the computer that you will be able to buy with $1000 now will be much better, much more effective, much more productive *etc.* than the computer that you could have bought with the same $1000 five years ago. However, open a current World Bank handbook and you will see that the present-day $1000, in terms of purchasing power parity (PPP), constitutes a significantly smaller sum than did the $1000 of five years ago. The point is that traditional measures of economic growth (above all, the GDP as measured in international PPP dollars) reflect less and less the actual growth of the standard of living (especially in more developed countries). Imagine a firm that in 2001 produced 1 million computers and sold them at $1000 a piece, in 2006 the same firm produced 1 million 100 thousand new, much more effective computers, but still sells them (due to increasing competition) at $1000 a piece (let us also imagine that the firm has managed to reduce production costs and thus increased both its profits and employees' salaries). How will this affect GDP, both in the country in which the firm operates, and in the world as a whole? In fact, the effect is most likely to be exactly zero. In 2006 the firm produces computers for a total price of 1100 million 2006 international PPP dollars. However, the World Bank will recalculate this sum into 2001 international PPP dollars and will find out that 1100 million 2006 international PPP dollars equal just 1000 million 2001 international PPP dollars. Thus, technological progress sufficient to raise the level of life of a significant number of people will in no way affect the World Bank GDP statistics, according to which it will appear that the above-mentioned technological advance has led to GDP increase at neither the country nor the world level.

The point is that the traditional GDP measures of production growth work really well when they are connected with the growth of consumption of scarce resources (including labor resources); however, if the production growth takes place without an increase in the consumption of scarce resources, it may well go undetected. The modified macromodel predicts such a situation when the World System's divergence from the blow-up regime will have resulted in the cessation of the resource-consuming World GDP production in its traditional measures, accompanied by the transition to exponential (in place of hyperbolic) growth of technology through which an increasing standard of living will be achieved without the growth of scarce-resource consumption.

Because the macrodynamics of the World System's development obey a set of rather simple laws having extremely simple mathematical descriptions, the macroproportions between the main indicators of that development can be described rather accurately with the following series of approximations:

$$N \sim S \sim l \sim u,$$
$$G \sim L \sim U \sim N^2 \sim S^2 \sim l^2 \sim u^2 \sim SN \sim etc.,$$

where (let us recollect) N is the world population; S is per capita surplus produced, at the given level of the World System's technological development, over the "hungry survival" level m that is necessary for simple (with zero growth) demographic reproduction; l is world literacy, the proportion of literate people among the adult (> 14 year old) population of the world; u is world urbanization, the proportion of the world population living in cities; G is the world GDP; L is the literate population of the world; and U is the urban population of the world. Yes, for the era of hyperbolic growth the absolute rate of growth of N (but, incidentally, also of S, l and u) in the long-run is described rather accurately[28] as kN^2 (Kapitza 1992, 1999); yet, with a comparable degree of accuracy it can be described as k_2SN, k_3S^2 or (apparently with a somehow smaller precision) as k_4G, k_5L, k_6U, k_7l^2, k_8u^2, *etc.*

It appears important to stress that the present-day decrease of the World System's growth rates differs radically from the decreases that inhered in oscillations of the past. This is not merely part of a new oscillation; rather, it is a phase transition to a new development regime that differs radically from the one typical of all previous history. Note, first of all, that all previous cases of reduction of world population growth took place against the background of catastrophic declines in the standard of living, and were caused mainly by increases in mortality as a result of various cataclysms – wars, famines, epidemics; and that after the end of such calamities the population, having restored its numbers in a relatively rapid way, returned to the earlier hyperbolic trajectory. In sharp contrast, the present day decline of the world population's growth rate takes place against the background of rapid economic growth and is produced by a radically different cause – the decline of fertility rates that is occurring precisely because rising standards of living for the majority of the World System's population have meant the growth of education, health care (including various methods and means of family planning), social security, *etc.* Decrease in the rate of growth of literacy and urbanization was not infrequent in the earlier epochs either; but in those epochs it was connected with economic decline, whereas now it takes place against the contrary background of rapid economic growth, and is connected to the closeness of the saturation level. Earlier declines, we might say, reflected a deficit of economic resources, whereas the present one reflects their abundance.

It appears necessary to stress that the models discussed above have been designed to describe long-term ("millennial") trends, whereas when we analyze social macrodynamics at shorter ("secular") time scales we also have to take in-

[28] However, for u the fit of this description appears to be smaller than for the rest of variables.

to account its cyclical (as well as stochastic) components; it is these components that will be the main task of the present part of our *Introduction to Social Macrodynamics*. To begin with, the actual dynamics typical for agrarian political-demographic cycles are usually the opposite of those that are theoretically described by "millennial" models and actually observed at the millennial scale. For example, as we shall see below, during agrarian political-demographic cycles the population normally grew much faster than technology, which naturally resulted in Malthusian dynamics: population growth was accompanied not by increase, but by decrease of per capita production, usually leading to political-demographic collapse and the start of a new cycle.

In Chapter 1, we shall review available mathematical models of political-demographic cycles. In Chapter 2, we shall consider in more detail political-demographic cycles in China, where long-term population dynamics have been recorded more thoroughly than elsewhere. In Chapter 3 we shall present our own model of pre-Industrial political-demographic cycles. Finally, in Chapter 4 we shall consider the interaction between long-term trends and cyclical dynamics.

Chapter 1

Secular Cycles

We believe that one of the most important recent findings in the study of the long-term dynamic social processes was the discovery of the political-demographic cycles as a basic feature of complex agrarian systems' dynamics.[1]

The presence of political-demographic cycles in the pre-modern history of Europe and China has been known for quite a long time (*e.g.*, Postan 1950, 1973; Abel 1974, 1980; Le Roy Ladurie 1974; Hodder 1978; Braudel 1973; Chao 1986; Cameron 1989; Goldstone 1991; Kul'pin 1990; Mugruzin 1986, 1994 *etc.*), and already in the 1980s more or less developed mathematical models of demographic cycles started to be produced (first of all for Chinese "dynastic cycles") (Usher 1989). At the moment we have a very considerable number of such models (Chu and Lee 1994; Nefedov 1999e, 2002a; 2004; S. Malkov, Kovalev, and A. Malkov 2000; S. Malkov and A. Malkov 2000; Malkov and Sergeev 2002, 2004a, 2004b; Malkov *et al.* 2002; Malkov 2002, 2003, 2004; Turchin 2003, 2005a).[2]

Recently the most important contributions to the development of the mathematical models of demographic cycles have been made by Sergey Nefedov, Peter Turchin and Sergey Malkov. What is important is that on the basis of their models Nefedov, Turchin and Malkov have managed to demonstrate that demographic cycles were a basic feature of complex agrarian systems (and not a specifically Chinese, or European phenomenon).

Nefedov (2004) starts with the population model developed by Raymond Pearl (1926) and described by the logistic equation suggested by Verhulst (Verhulst 1838; see also, *e.g.*, Riznichenko 2002; Korotayev, Malkov, and Khaltourina 2006):

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[1] As these cycles are of an order of 1–2 centuries, it was suggested by Turchin (2003, 2005b) to denote them as "secular cycles". We would also like to acknowledge that it also was Peter Turchin who in October 2002 suggested to us to denote the macrotrends we are dealing with in this *Introduction to Social Macrodynamics* as "millennial trends".

[2] There are also a rather large number of pre-industrial population-economy dynamic models designed to account for "the escape from Malthusian Trap", rather than for the structure of pre-industrial population cycles (Artzrouni and Komlos 1985; Steinmann and Komlos 1988; Komlos and Artzrouni 1990; Steinmann, Prskawetz, and Feichtinger 1998; Wood 1998; Kögel and Prskawetz 2001).

$$\frac{dN}{dt} = r(1 - \frac{N}{C})N \quad ,$$

where N is population, r is rate of natural growth, and C is maximum carrying capacity.

This results in dynamics demonstrated in Diagram 1.1[3]:

Diagram 1.1. Dynamics Generated by Raymond Pearl's Model

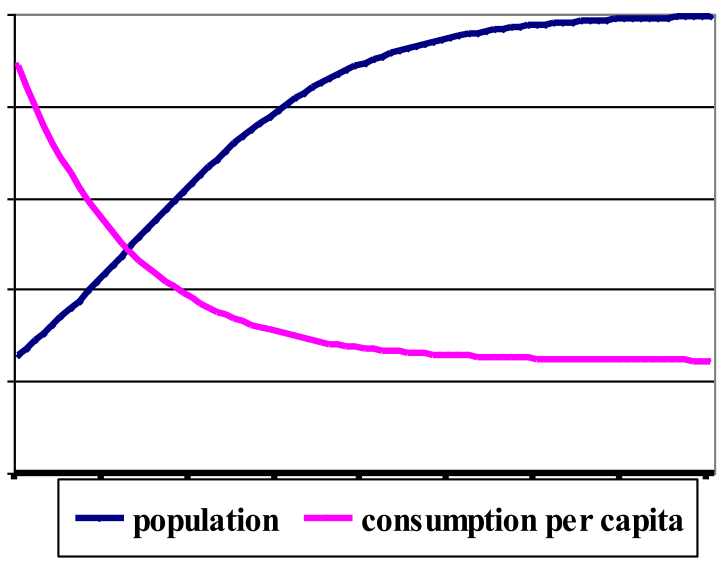


Fig. 1. The logistics curve and the curve of consumption per capita

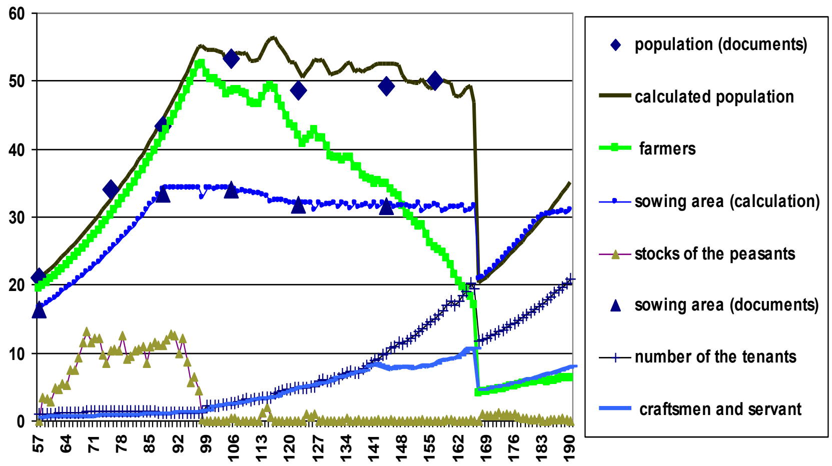
Starting from this basis Nefedov developed his mathematical model of pre-industrial sociodemographic cycles. The basic logic of these models looks as follows: after the population reaches the ceiling of the carrying capacity of land its growth rate declines toward zero values and the system experiences significant stress with decline of the living standards of common population, increasing severity of famines, growing rebellions *etc.* As has been shown by Nefedov,

[3] From Nefedov 2004.

most complex agrarian systems had considerable reserves for stability, however, within 50–150 years these reserves usually got exhausted and the system experienced a demographic collapse, when increasingly severe famines, epidemics, increasing internal warfare and other disasters led to a considerable decline of population. As a result of this collapse, free resources became available, per capita production and consumption considerably increased, the population growth resumed and a new demographic cycle started. It has turned out to be possible to model these dynamics mathematically in a rather effective way.

It seems necessary to stress that a new generation of models has moved far beyond this basic logic. For example, models now describe effects of class structure and elite overproduction; the new models predict dynamics of a great number of variables like food prices, urbanization levels, growth of wealth differentiation and so on. These models have achieved a rather close fit with observed data. As an example, we present a diagram from a recent article by Nefedov (2004) displaying the social and economic dynamics for the East Han cycle predicted by Nefedov's model and the ones actually observed in historical sources (see Diagram 1.2):

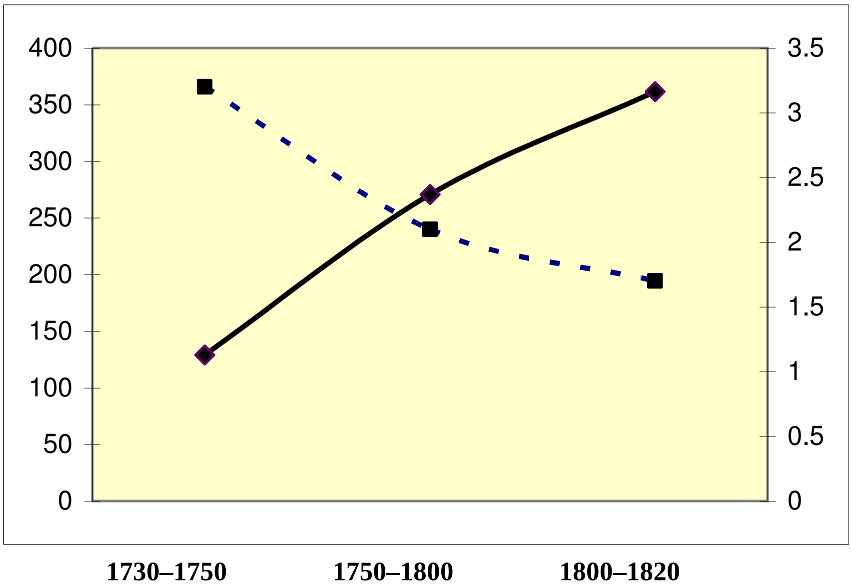
Diagram 1.2. Social and Economic Dynamics of China in the Later Han Period (Nefedov 2004: 77)



As we have already mentioned, a new generation of demographic cycle models has made it possible to show that demographic cycles were a basic feature of complex agrarian systems (and not a specifically Chinese, or European phenomenon).

It is not very often that we have direct evidence for long-term trends for both population numbers and consumption rates. It is very rare that we have long-term data on both variable dynamics within a cycle (as for Qing China, see Diagram 1.3):

Diagram 1.3. Population and Consumption in China in the Qing Epoch



- - - ■ - - - consumption (daily wages, liters of rice)
—♦— population (millions)

NOTE: Adopted from Nefedov 2003: 5. The data on daily wages are from Chao 1986: 218–9. The data on population are from Zhao and Xie 1988: 541–2.

Much more frequently we have data just for one of such variables. Thus, for most Chinese dynastic cycles we have data on population dynamics (see, *e.g.*, Diagrams 1.4 and 1.5), and usually they display dynamics quite close to the those predicted by demographic cycle models:

Diagram 1.4. Population in Early Tang China (number of households in millions) (Nefedov 1999c. Fig. 2).

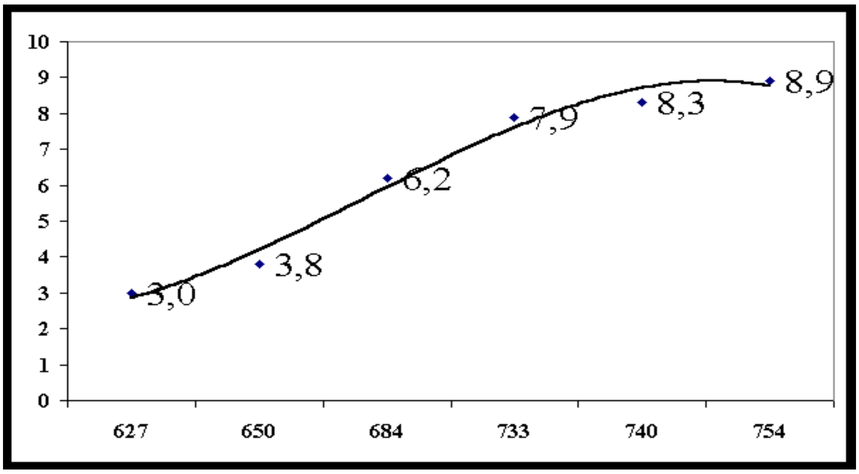
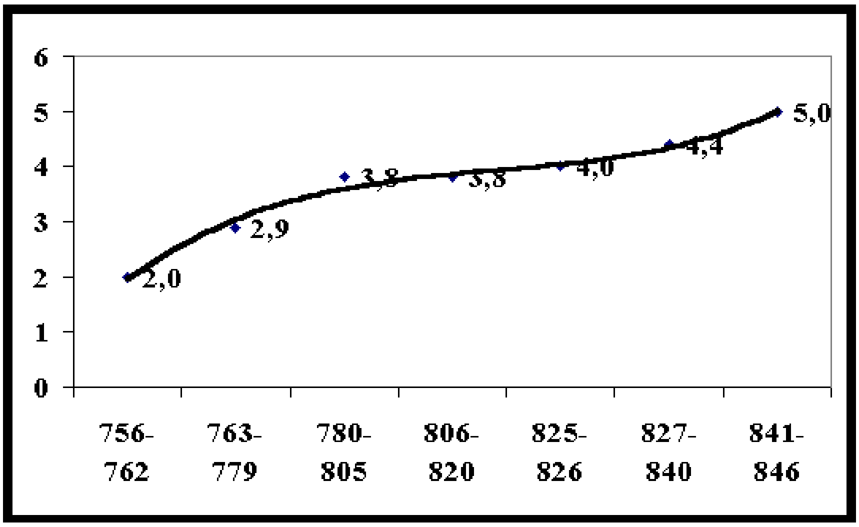


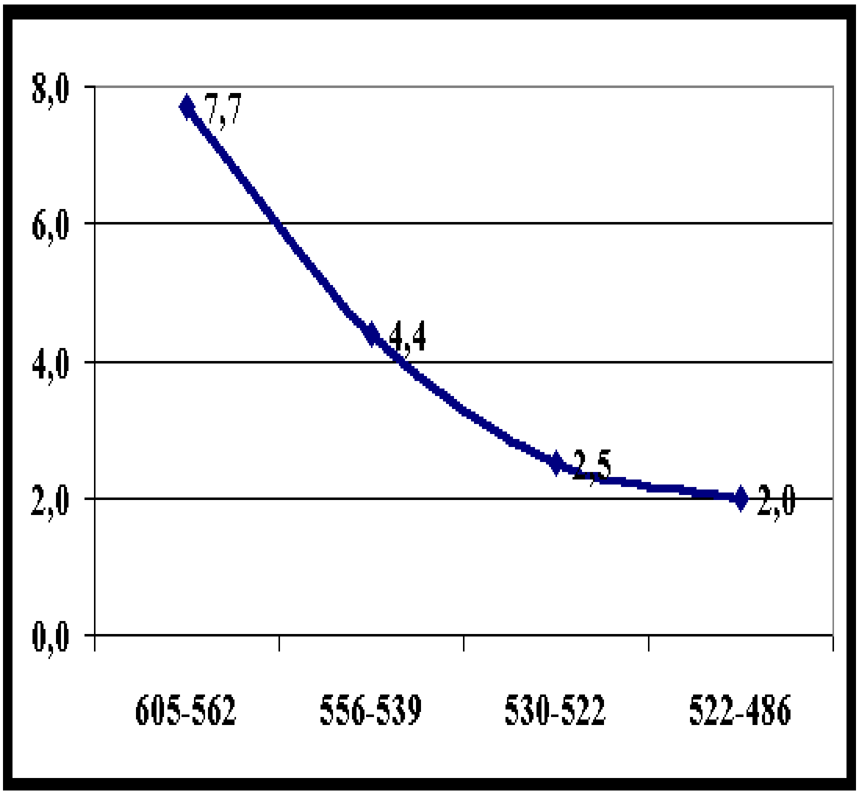
Diagram 1.5. Population in Late Tang China (the number of households in millions) (Nefedov 1999c. Fig. 3).



Note that the form of the population curves is quite close to the one predicted by Nefedov's model.

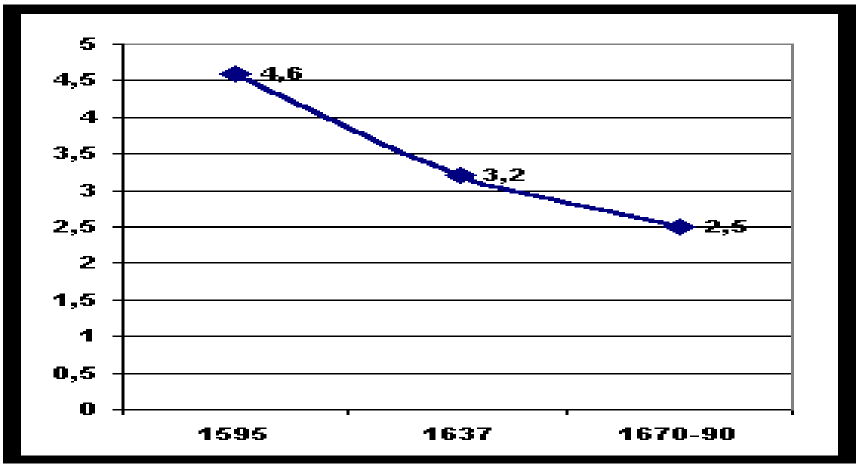
We have practically no long-term population data outside China (and, to some extent, Europe), and this made it difficult to detect demographic cycles outside Europe and China. However, not so infrequently we can find long-term data on some other variables predicted by Nefedov's model (first of all per capita consumption rates), and quite regularly they have just the form predicted by Nefedov's model (see, *e.g.*, Diagrams 1.6–8):

Diagram 1.6. Consumption Dynamics in Babylonia in the 6th – early 5th centuries BC (Nefedov 2003: Fig. 4)



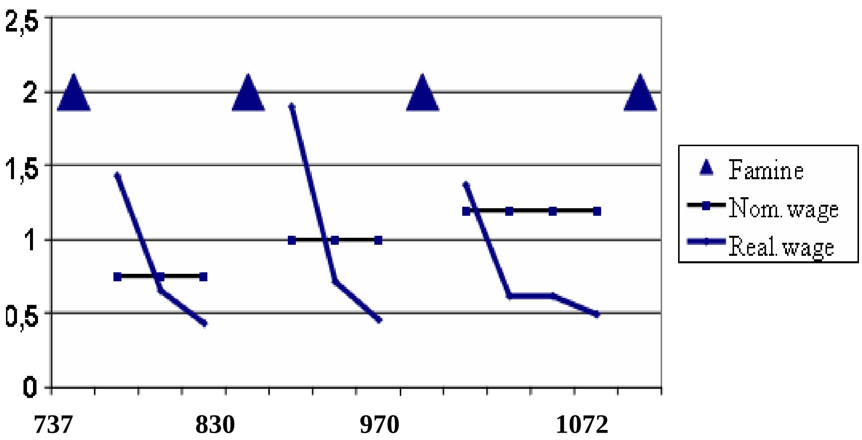
NOTE: The numbers indicate the amount of barley in liters that an unskilled worker could buy on his daily wage.

Diagram 1.7. Consumption Dynamics in Northern India in the late 16th – 17th centuries (Nefedov 2003: Fig. 12).



NOTE: The numbers indicate the amount of wheat in liters that an unskilled worker could buy for his daily wage.

Diagram 1.8. Consumption Dynamics in Egypt in the early 8th – 11th centuries (Nefedov 2003: Fig. 8)



NOTE: Daily wages of unskilled workers. The data on nominal wages are from Ashtor 1976: 201. The real wages were calculated by Nefedov as amount of wheat (in decaliters), which an unskilled worker could buy for his daily wage.

Using such indirect data, as well as his system of qualitative indicators of various phases of demographic cycles Nefedov (1999a, 1999b, 1999c, 1999d, 1999e, 2000, 2001a, 2001b, 2002a, 2002b, 2003, 2004, 2005 *etc.*) has managed to detect more than 40 demographic cycles in the history of various ancient and medieval societies of Eurasia and North Africa, thus demonstrating that the demographic cycles are not specific for Chinese and European history only, but should be regarded as a general feature of complex agrarian system dynamics.

We would like to discuss in some detail three approaches to modeling of demographic cycles: Turchin's (2003) models, another by Chu and Lee (1994), and finally, the model of Nefedov (1999e, 2002a; 2004).

The "demographic-fiscal" model developed by Turchin (2003: 118–27, 208–13) connects population dynamics, state resources and internal warfare. In this model the elites controlling the state are not assumed to be selfish. It is rather assumed "that the state has a positive effect on population dynamics; specifically, it increases *k* [the carrying capacity]" (Turchin 2003: 122). "There are many mechanisms by which the state can increase the carrying capacity… The strong state protects the productive population from external and internal (banditry, civil war) threats, and thus allows the whole cultivable area to be put into production… The second general mechanism is that states often invest in increasing agricultural productivity by constructing irrigation canals and roads, by implementing flood control measures, by clearing land from forests, *etc.* Again, the end result of these measures is an increase in the number of people that can be gainfully employed growing food, *i.e.*, the carrying capacity" (Turchin 2003: 120–1). Thus the depletion of state resources and state breakdown are assumed to be leading to the decline of the carrying capacity and, thus, demographic collapse. As in all the other demographic cycle models the per capita rate of surplus production is assumed to be a declining function of population numbers, whereas the state expenditures are assumed to be proportional to population size. Within this model "the rate of change of *S* [state resources] is determined by the balance of two opposing forces: revenues and expenditures. When *N* [population] is low, increasing it results in greater revenues (more workers means more taxes). The growth in state expenditures lags behind the revenues, and the state's surplus accumulates. As *N* increases, however, the growth in revenues ceases, and actually begins to decline. This is a result of diminishing returns on agricultural labor. However, the expenditures continue to mount. At population density $N = N_{crit}$, the revenues and expenditures become (briefly) balanced. Unfortunately, population growth continues toward the carrying capacity, *k*, and the gap between the state's expenditures and revenues rapidly becomes catastrophic. As a result, the state quickly spends any resources that have been accumulated during better times. When *S* becomes zero, the state is unable to pay the army, the bureaucrats, and maintain infrastructure: the state collapses", which leads to a radical decline of the carrying capacity of land and demographic collapse (Turchin 2003: 123).

Turchin has also developed a number of elegant models of population dynamics, where the peasant-elite interaction plays the role of the main mechanism of state breakdown. When the population size becomes large, food supplies are exhausted and the elite multiplies out of control – then state collapse is observed, followed by a significant decrease in the number of peasants. A large number of elite cannot be supported by a shrunken population, so eventually the elite decreases, and the cycle of growth starts over. A resulting feature is that we do not observe the population to climb up to its carrying capacity and saturate at a certain level before a collapse (for a more detailed analysis of these models see the next issue of our *Introduction to Social Macrodynamics* [Korotayev and Khaltourina 2006]). Also, the elite behaves in a strictly selfish manner; it does not play a role in food redistribution (*e.g.*, to provide food for starving people during time of famine); this mechanism, however, is important when modeling Chinese demographic cycles.

The interesting model of Chu and Lee combines elements of mathematical modeling and statistical analysis/best fit approach. The main idea is very attractive. The population consists of rulers, peasants and bandits (rulers being equated with soldiers, drafted every year at a constant rate). The population has some intrinsic growth rate, that is, the rate at which it increases given unlimited resources. As the density increases, the resources get scarce, and the growth rate decreases (this is an effect of overpopulation). At the same time, there is a flux of people from peasants to bandits and *vice versa*. Each person faces a choice of either working in the field or "defecting" and getting his food by means of force. The soldiers are supported by taxation and they fight the bandits. The rational choice is based on evaluating the "utility function" of peasants and bandits and it depends on external circumstances such as the degree to which agricultural resources are damaged by warfare. The utility function is a combination of the food share received and the probability of survival.

As the density of the population grows, it becomes more and more likely that people choose to become bandits and fight for their food instead of growing it. This leads to the reduction in population numbers and the cycle starts over.

Chu and Lee did not specify their model to the extent where it can be implemented directly. Instead, they used it as a tool to improve the fitting of real historical data. Information on warfare and winter temperatures was included in the form of exogenous variables, and the frequency of peasant rebellions was modeled based on the expected fraction of the rebels, calculated by the model. This gave an excellent fit to the existing data.

Another interesting idea presented by Chu and Li are the two possible explanations of the irregularity of the historical political-demographic cycles. One explanation is simply the ("external") stochasticity of the climatic conditions. The other one is the intrinsic chaotic behavior of the dynamics system. Depending on parameter values, the simplified system analyzed by the authors has been shown to undergo a series of period-doubling bifurcations and a transition to chaos.

What is slightly disappointing is that the authors did not include the effects of an annually changing crop yield (which is a function of climate fluctuations). Nor did they include the positive role of the ruling class in food redistribution (which is especially salient precisely in the Chinese case on which their model is based). Moreover, the historical temperature data proved to be irrelevant for the fit. These points will be addressed in more detail when we talk about our model (see Chapter 3 below).

Nefedov, who incorporated stochastic effects of year-to-year food yields on the population dynamics, has taken another approach. He noticed that as the population reaches the carrying capacity of land, and food storages become depleted, then random effects of good and bad years can play a significant role in the dynamics. As food becomes very scarce because of, say, a bad winter, people tend to sell their land and leave for cities, or join bands of rebels. In idealized conditions, that is, given a perfectly constant food yield, no cycle is expected. However, a bad harvest triggers a mechanism of collapse with a significant reduction in population number. Nefedov's models have several interesting components. For example, because of the increasing numbers of people leaving the land as population density increases, we expect to see an intense growth of cities, which is confirmed by historical observations. What seems to be missing from Nefedov's models is the direct role of rebellion and internal warfare on the cycle behavior. If only economic factors are taken into account, then there seems to be no inertia in the dynamics, and each demographic catastrophe is followed immediately by a new rise. As we shall see below, this plainly contradicts historical data where "intercycle" periods of variable (but always significant) length are observed.

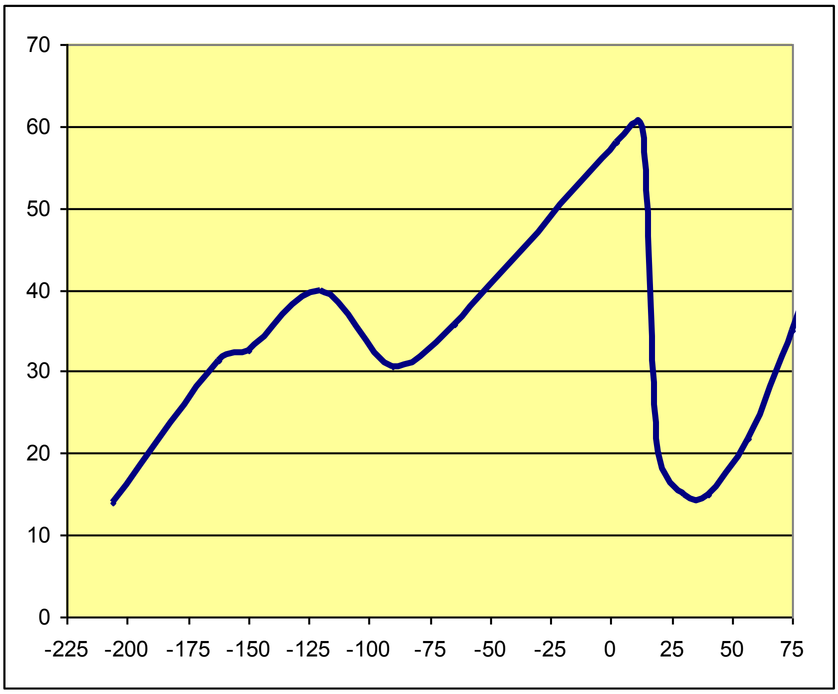
In the next chapter we shall consider in more detail political-demographic cycles in China, where long-term population dynamics have been recorded more thoroughly than elsewhere.

Chapter 2

Historical Population Dynamics in China: Some Observations

The estimates of Chinese population dynamics during the Western Han dynasty (206 BCE – 9 CE) look as follows (see Diagram 2.1):

Diagram 2.1. Population of China in millions: Western Han Cycle (206 BCE – 9 CE)

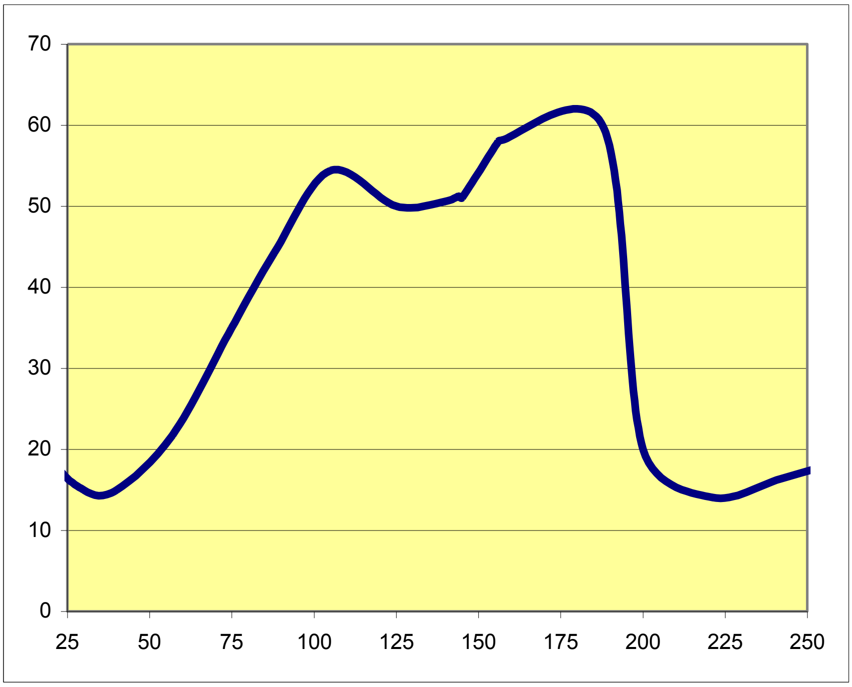


NOTE: estimates of Zhao and Xie (1988: 536).

For most of the cycle these are estimates. However, we have more or less reliable census data for 2 and 57 CE (*e.g.*, Bielenstein 1947: 126, 1986: 240; Durand 1960: 216; Loewe 1986b: 206). We also have abundant historical data evidencing a substantial period of extreme political instability separating the demographic collapse of the second decade (precipitated by the catastrophic flood of 11 CE) from the period of new demographic growth (*e.g.*, Bielenstein 1986). Thus, though we cannot be sure about the exact shape of the demographic cycle curve for Western Han, we can be quite confident about the fact that the new phase of demographic growth did not begin in this case immediately after demographic collapse.

Chinese population dynamics during the Eastern Han dynasty (25 – 220 CE) are delineated below in Diagram 2.2:

Diagram 2.2. Population of China in millions: Eastern Han Cycle (25 – 220 CE)



NOTE: estimates of Zhao and Xie (1988: 536).

For this cycle we have census data for 9 years (57, 75, 88, 105, 125, 140, 144, 145, 146, and 156 CE [*e.g.*, Bielenstein 1947: 126, 1986: 240–2; Durand 1960: 216; Loewe 1986c: 485, *etc.*]), which, in fact, document rather well two main phases of the cycle – a rapid growth from 21,007,820 in 57 CE to 53,256,229 in

105 CE, followed by population stagnation at the level strikingly close to the one from which the Western Han demographic collapse took place.[1]

Note that during the first phase the average annual growth rate was quite high, but in no way fantastic – just 2%, which according to Turchin (2003: 125) is just a normal growth rate for pre-industrial agrarian populations when they are adequately provided with resources in conditions of political stability. In the modern world such figures can, of course, be much higher. *E.g.*, in 1960 – 1962 in Costa Rica and 1965, 1967, and 1970 in Kuwait the natural annual population growth rate exceeded 4%. Even in poverty-stricken Yemen it was 3.7% on average in the last two decades of the 20th century, and in really poor Niger it was 3.3%. In Guinea the average growth rate in this period was 2.6%, whereas the life expectancy at birth in this country in 1980 was even lower (40 years)[2] than the one estimated for early Qing China (*e.g.*, Harrell and Pullum 1995: 148) when (according to Zhao and Xie 1988: 540–1) the population growth also approached 2%.

Hence, we do not see any grounds to exclude the possibility that between 57 and 105 CE the Chinese population, well provided with resources in conditions of considerable political stability and a well-functioning state apparatus, could experience 2% a year growth (at least for a few years). Note that the second half of the 1st century in China was described by contemporaries as indeed rather prosperous and stable (Lee Mabel Ping-hua 1921: 178–9; Bokshchanin and Ling 1980: 30; Krjukov *et al.* 1983: 32; Maljavin 1983: 30; Loewe 1986a: 292–7; Nefedov 2002a: 140). The state had sufficient resources and infrastructure to provide adequate relief in critical situations.[3] It is remarkable that for the post-105 CE period we have much evidence for overpopulation, poverty, state's depletion of resources, and its growing inability to provide sufficient relief in critical years (Lee Mabel Ping-hua 1921: 182–6; Maljavin 1983: 28–9, 77–80; Ebrey 1986: 621; Loewe 1986a: 301–16; Nefedov 2002a: 140–2), all of which correlates very well with the census data on the population stagnation at the carrying capacity of land level in 105 – 156 CE. Thus, though the actual popula-

[1] That the population stabilized in the Eastern Han period at a level lower than the one attested for Western Han might be somehow connected with the loss of some territories to Northern neighbors, and the incomplete recovery of lands controlled by Western Han in Southernmost China during the Eastern Han period. Note that the maximum area of cultivated land attested for Eastern Han (746,000,000 mu in 105 CE) is still lower than the one attested for Western Han (827,000,000 mu in 2 CE) (the data are compiled by Nefedov 2002a on the basis of Lee 1921: 436; Kul'pin 1990: 216; Krjukov *et al.* 1983: 41).

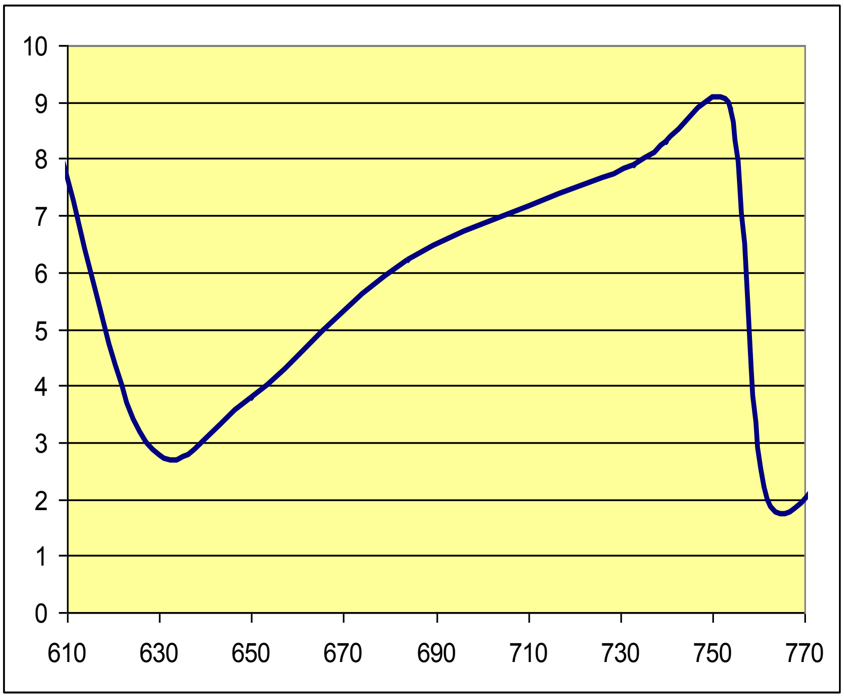
[2] The data on modern countries are from *World Development Indicators* (World Bank 2005).

[3] "The government was remarkably successful in coping with each crisis. Wang Ch'ung (A.D. 27 – ca. 100), a caustic critic who was seldom generous or complimentary in his judgments, thought that no ancient ruler could have handled relief programs any better than the senior statesman Ti-wu Lun (fl. A. D. 40 – 85) had during the cattle epidemic [of 76 CE – A.K., A.M., D.K.]" (Ebrey 1986: 620).

tion growth rate in 57 – 105 CE may well still have been below 2%,[4] in general, the census data seem to capture quite adequately the population dynamics during the first two main phases of the Eastern Han. We have also abundant historical evidence for demographic collapse and a very prolonged period of internal warfare and political instability at the end of Han period, as well as for a long time after it (*e.g.*, Bokshchanin and Ling 1980: 116; Krjukov, Maljavin, and Sofronov 1979: 13–37; Maljavin 1982; Beck 1986; Schmidt-Glintzer 1999: 34–55; Fairbank 1992: 72–3; Wright 2001: 60–1, *etc.*).

Chinese population dynamics during the Early T'ang cycle (618 – 755 CE) are delineated below in Diagram 2.3a:

Diagram 2.3a. Population of China in millions of households: Early T'ang Cycle (618 – 755 CE)

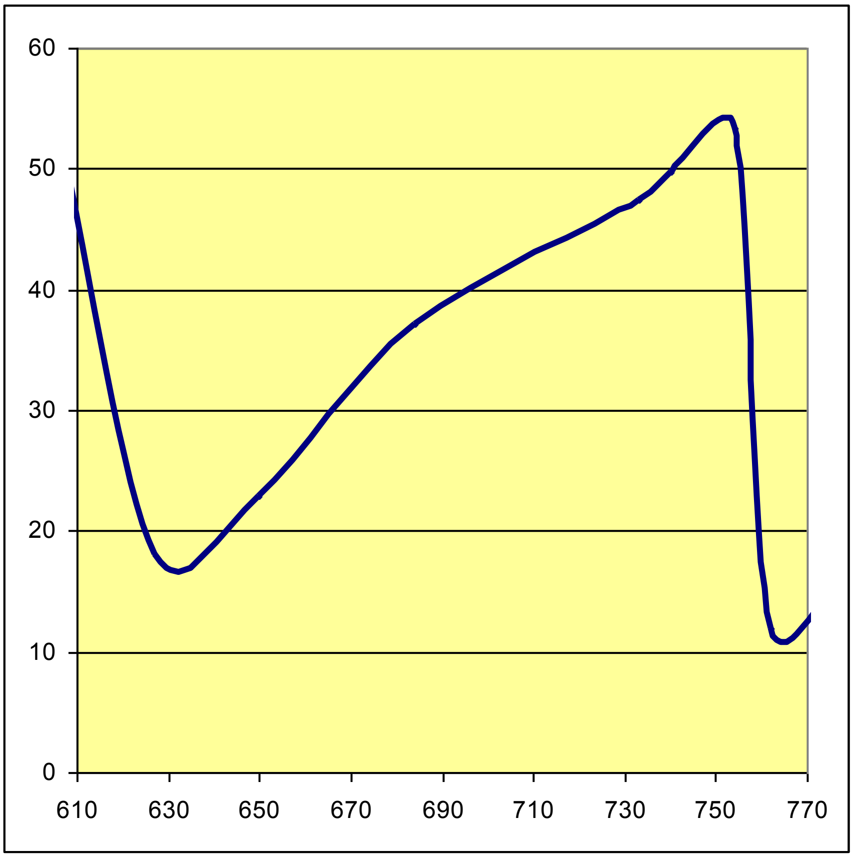


NOTE: The data are from Nefedov 1999c: 5; 2003: Fig. 10, on the basis of Lee Mabel Ping-hua 1921: 436, cp. Durand 1960: 223; Zhao and Xie 1988: 537.

[4] An alternative explanation could be that in 57 CE there was still a considerable underregistration of population, and the growth of registered population between 57 and 105 CE is to be accounted for both by the actual population growth and increase in the proportion of registered population (*e.g.*, Durand 1960: 218).

Assuming 6 persons per household, this corresponds to the following population dynamics during this cycle (see Diagram 2.3b):

Diagram 2.3b. Population of China in millions:
Early T'ang Cycle (618 – 755 CE)



There is much historical evidence of a significant period of political instability following the late Sui demographic collapse (*e.g.*, Wright 1979: 128–49; Wechsler 1979a). In fact, there is not much doubt that the population of China did not decline as dramatically as would be suggested by a straightforward comparison between the Sui census of 606 CE, which listed more than 46 million persons and the first T'ang census (627 CE), which registered just 12,000,000 (*e.g.*, Durand 1960: 223).

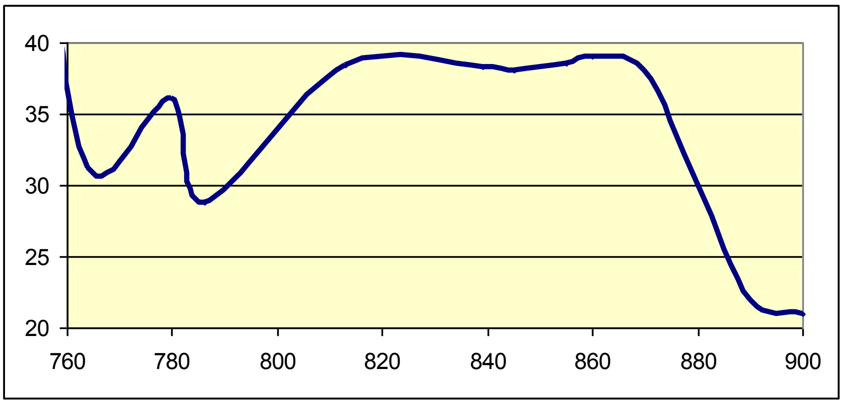
No doubt, this apparent decline is to be accounted for to some extent by underregistration (*e.g.*, Wechsler 1979b: 208–9; Twitchett and Wechsler 1979: 277). However, the rapid growth of registered households up to the early 660s seems to reflect to a very considerable degree actual population growth. Note that "T'ai-tsung's reign had in general been a period of prosperity and low prices, and these continued until the early 660s" (Twitchett and Wechsler 1979: 277; see also, *e.g.*, Wechsler 1979b: 209–10); additionally, for this period we have evidence of free resources (first of all, uncultivated land) still being available (*e.g.*, Lee Mabel Ping-hua 1921: 233; Shang Yue 1959: 205; Nefedov 1999c: 4), whereas the annual population growth rate for this period implied by the census data is just c. 2%, which is, as has been already mentioned above, just a normal growth rate for pre-industrial agrarian populations when they are adequately provided with resources in conditions of political stability.

On the other hand, for the subsequent period we have growing evidence of overpopulation and famines (*e.g.*, Twitchett and Wechsler 1979: 278; Lee Mabel Ping-hua 1921: 236–7; Nefedov 1999c: 4). It appears that this was the Empress Wu's reign (both unofficial and official), when the growth of registered household numbers seems to be accounted for more by the successes in registration rather than by actual population growth (see, *e.g.*, Guisso 1979: 293, 313). Thus, the actual decline of the population growth rate during this phase might have been much more considerable than is indicated in Diagram 2.4.

On the other hand, the accelerating population growth in the 730s – early 750s suggested by the T'ang census figures seems to reflect actual population dynamics rather than mere registration progress, and appears to have resulted from a series of more or less successful (at least in the short run) administrative reforms of the Hsüan-tsung government (Twitchett 1979: 400–1, 419–20), as well as, possibly, from technological innovations (*e.g.*, Bray 1984: 114), which helped to increase the carrying capacity of land and temporarily relieve the demographic crisis, though they did not much delay the demographic collapse ("the An Lushan Rebellion", caused, however, mostly by the imperfections of the Hsüan-tsung military organization [Peterson 1979: 468–74]). However, such innovations (which might also account for a short period of renewed population growth at the pre-collapse phase of the Eastern Han demographic cycle [*e.g.*, Bray 1984: 587–97]) were immensely important, as they created an overall millennial trend towards the rise of the carrying capacity of land (and, consequently, of population numbers). In fact, as we shall see below, in Sung China such mid-cycle innovations (both administrative and technological) turned out to be successful to such an extent that they resulted in the mid-cycle demographic crisis leading not to a demographic collapse, but to the radical rise of the overall carrying capacity of land.

Chinese population dynamics during the Late T'ang cycle (763 – 880 CE) are delineated below in Diagram 2.4:

Diagram 2.4. Estimated Population of China in millions: Late T'ang Cycle (763 – 880 CE)



NOTE: estimates of Zhao and Xie (1988: 537).

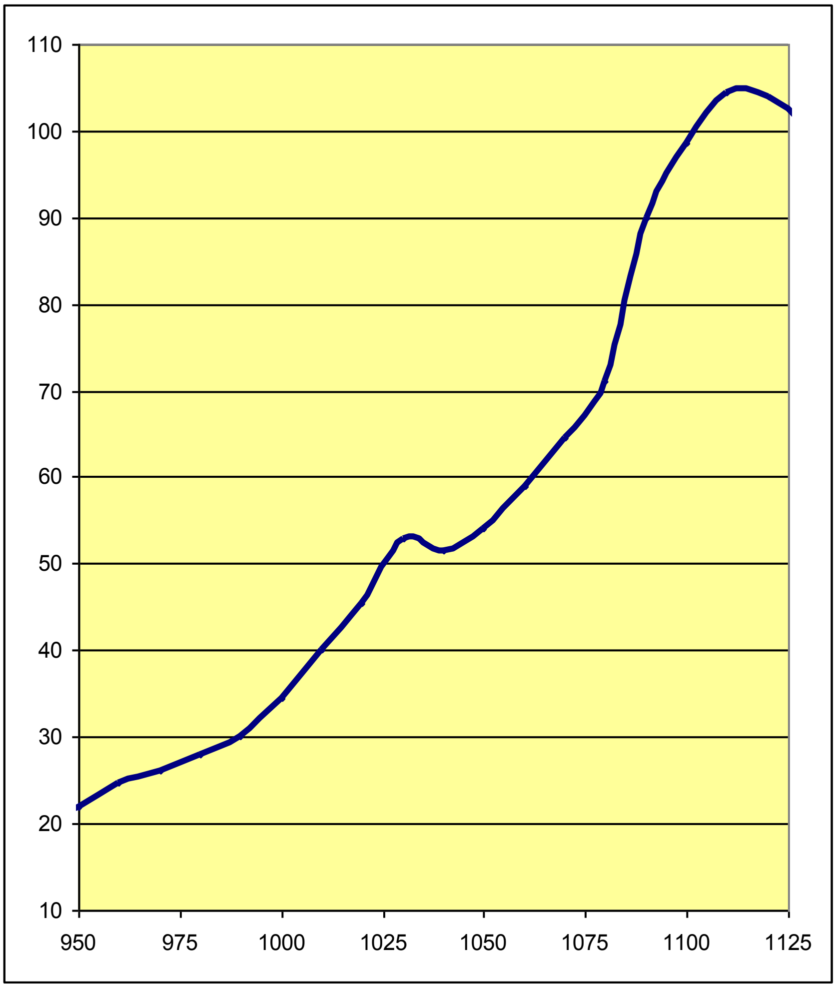
The post-780 population decline reflected both in Zhao and Xie estimates and in the T'ang census data (*e.g.*, Durand 1960: 223) is connected with the so-called Ho-pei rebellions of 781 – 786, which could be regarded as a direct continuation of the An Lushan Rebellion events (Peterson 1979: 500–7; Dalby 1979: 582–6). Again there is no doubt that the population of China did not decline as dramatically as this would be suggested by a straightforward comparison between the census of 755 CE, which listed almost 53 million persons and the census of 764 CE, which registered just 16,900,000 (*e.g.*, Durand 1960: 223). The actual population decline might have been even less than was estimated by Zhao and Xie, as the underregistration in the post-An Lushan T'ang Empire was especially heavy, because the T'ang administration did not have effective control over many vast and populous territories – above all, in Ho-pei (*e.g.*, Durand 1960: 223; Peterson 1979: 485).

Nobody, however, seems to doubt that the population of China remained well below the early T'ang maximum during the late T'ang cycle, though we might never learn the exact difference between those two levels. There is still some evidence of overpopulation, especially in the Lower Yangtze area (Lee Mabel Ping-hua 1921: 260; Nefedov 1999c: 7; Peterson 1979: 552–3). The fact that the demographic crisis began during the late T'ang cycle at a level far below the one reached by early T'ang might be connected with the fact that the overall carrying capacity of land declined as a result of the central administration heavily reduced ability to redistribute excessive population and resources between overpopulated and underpopulated areas. There is much historical evidence for a very long period of extensive internal warfare at the end of the T'ang period and during the T'ang – Sung intercycle (*e.g.*, Somers 1979;

Schmidt-Glintzer 1999: 70–8; Fairbank 1992: 72–3; Wright 2001: 83–8, *etc.*). On the other hand, it is not entirely clear that the Late T'ang period should not be regarded as a part of the T'ang – Sung intercycle rather than a separate cycle (*e.g.*, Fairbank 1992: 86).

Chinese population dynamics during the Sung cycle are delineated below in Diagram 2.5:

Diagram 2.5. Estimated Population of China in millions: Sung "Cycle"



NOTE: estimates of Nefedov (1999c: 10).

In fact, the official Sung census of 1103 lists only 45.98 million persons (but 20.52 million households) (*e.g.*, Durand 1960: 226). However, "the Sung statistics are unique in that they show very small average numbers of persons per household, ranging in most years from only 2.0 to 2.3 persons… The more probable explanation seems to be that the statistics of persons were limited to the male sex. It is unlikely that even the males were completely enumerated…" (Durand 1960: 227). In general, there seems to be an unusually high degree of consensus that in the early 11th century the population of China was over 100 million (*e.g.*, Ho 1959: 172; Durand 1960: 226; Banister 1987: 4; Fairbank 1992: 89; Feuerwerker 1995: 50–1; Deng 1999: 191; Mote 1999: 164; Nefedov 1999c: 10, etc).[5]

On the other hand, the official Sung statistics appear to describe adequately the overall trends of population dynamics[6] during this period. Indeed the Sung census suggest a relatively rapid population growth rate in early decades of the cycle, which correlate quite well with evidence of relative prosperity, relatively high consumption rates and availability of free resources during this period (Lee Mabel Ping-hua 1921: 270–6; Shang Yue 1959: 287; Smolin 1974: 100–1; Nefedov 1999c: 9, *etc.*).

This growth continues up to 1006, then it slows down but still continues, with some setbacks, until 1029, for which year the Sung census registered 10.56 million households (which corresponds to 53–64 million persons). After this, for three decades population stagnates, or even shows negative dynamics. This is rather expected, as by the late 1020s Chinese population appears to have approached the old ceiling of the carrying capacity of land, that is, the level at which the demographic collapses took place during earlier demographic cycles (starting from Western Han). Indeed, for the Sung mid-phase we have extensive evidence for all the symptoms of sociodemographic crisis preceding demographic collapse – undernutrition, rising rebellions *etc.* (*e.g.*, Lee Mabel Ping-hua 1921: 281–2; Smolin 1974: 311–57; Nefedov 1999c: 9, *etc.*).

However, the Sung mid-phase demographic crisis resulted not in a demographic collapse, but in the non-catastrophic solution of the crisis through the radical rise of the carrying capacity of land. For Sung we have extensive evidence for numerous administrative and state-sponsored (as well as spontaneous) technological innovations leading to this rise, culminating in Wang Anshi reforms (Ho 1956, 1959: 169–70, 177–8; Shiba 1970: 50; Chou 1974: 93–5; Bray 1984: 79, 113–4, 294–5, 491–4, 597–600; Mote 1999: 165). One of the most

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5 As the average household size at this time is usually estimated between 5.0 and 6.0, the different estimates, *e.g.* for 1103 CE, also vary between 103 and 123 million persons; this still gives a rather clear idea about the general level reached by the Chinese population by the early 11th century (that is why we speak about an unusually high level of consensus – *e.g.*, as we shall see below, for the early 17th century estimates vary between 99 and 300 million).

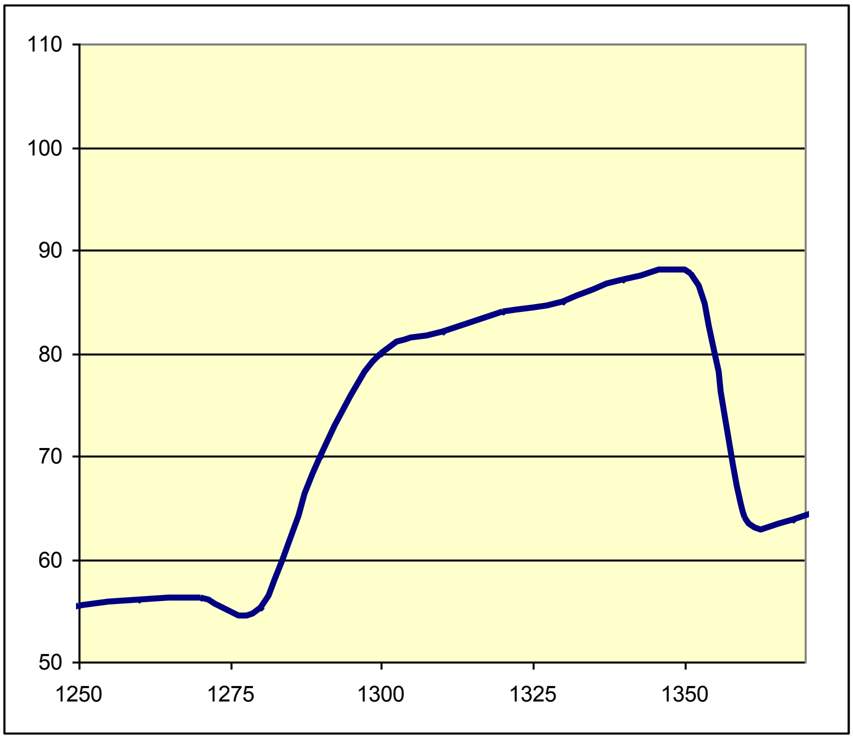
6 Diagram 2.5 demonstrates these dynamics just according to these statistics, but with the number of households according to the Sung census having been multiplied by 5.0 (Nefedov's estimation of the average number of persons per household during this period).

spectacular and effective among them was the quite conscious, systematic and well-organized introduction and diffusion of new varieties of quick-ripening rices from Champa, accompanied by the peasants' development of still new varieties (Ho 1956; Perkins 1969: 38; Shiba 1970: 50; Bray 1984: 491–4, 598). In the early 12th century China appears to have reached a new ceiling for the carrying capacity of land, which resulted in a new sociodemographic crisis (Smolin 1974: 420–39; Nefedov 1999c: 10–1).

There are no grounds to exclude the possibility that Sung China had potential to solve this crisis too in a non-catastrophic way, eventually even escaping from the "Malthusian trap" (see, *e.g.*, Meliantsev 1996). However, the Sung cycle was interrupted quite artificially by exogenous forces, namely, by the Jurchen and finally Mongol conquests.

Chinese population dynamics during the Yüan cycle are delineated below in Diagram 2.6:

Diagram 2.6. Estimated Population of China in millions: Yüan Cycle



NOTE: estimates of Zhao and Xie (1988: 539).

The Yüan cycle was unusually short, and the population of China does not appear to have reached the Sung level.

There seems to be a rather straightforward and very convincing explanation for this:

"…It may be worth recalling that the fourteenth century was calamitous everywhere. Within and beyond the various Mongol empires, from Iceland and England at one end of Eurasia to Japan at the other, societies were suffering plagues, famines, agricultural decline, depopulation, and civil upheaval. Few societies were spared at least some of the symptoms. China was spared none of them. No fewer than thirty-six years in the fourteenth century had exceptionally severe winters, more than any other century on record. In the greater Yellow River region, major floods and droughts[7] seem to have occurred with unprecedented frequency in the fourteenth century. Serious epidemics broke out in the 1340s and 1350s. Famines were recorded for almost every year of Toghōn Temür's reign [1333 – 1368 – A.K., A.M., D.K.], leading to great mortality and costing the government vast sums in relief. These natural disasters created huge numbers of uprooted and impoverished people, fodder for the revolts that wracked the realm in the 1350s… It might well be the case that the long-term cumulative effects of such repeated natural calamities were too great for any government to handle and that if normal conditions had prevailed in China, the Yüan dynasty might have lasted much longer than it did" (Dardess 1994: 585–6).

Indeed, in pre-industrial history we appear to find a correlation between annual temperatures and population numbers, whereby radical declines in annual temperatures correlated with considerable declines in population numbers (or slowing down of population growth rates) in Europe, China, as well as in the world population numbers (*e.g.*, Malkov 2002: 297). Malkov provides the following explanation for this correlation: "Global warming appears to have led to growth of the demographic carrying capacities of territories (enhancing the survival conditions within given modes of nature exploitation), which resulted in growing population densities. On the contrary, the cooling resulted in relative overpopulation (excessive demographic pressure on the territory as a result of the decline of food production basis caused by the drop in the yields), which led to mass migrations, social cataclysms, wars, and, consequently to the decreasing population densities…" (Malkov 2002: 297).

Thus, in the 14th century the catastrophic decrease in annual temperatures (*e.g.*, Malkov 2002: Fig. 6) appears to have resulted in the decrease of the carrying capacities in most parts of Eurasia, leading (in conjunction with pandemics) to shortening of demographic cycles and the chain of premature demographic collapses. And China here seems to have been no exception.

There is much historical evidence for a significant period of extensive internal warfare and political instability during the Yüan – Ming transition (*e.g.*, Mote 1988; 1999: 517–48; Dreyer 1988: 58–97; Dardess 1994: 580–4).

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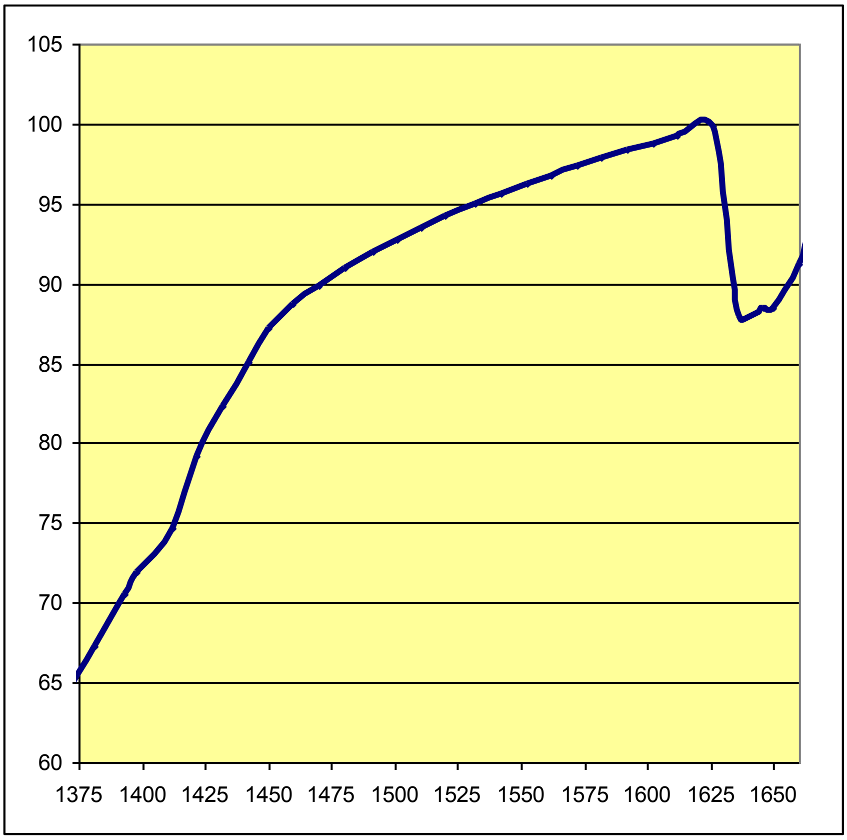
[7] Note that in many parts of Eurasia the global cooling was accompanied (rather counterintuitively) just by droughts and floods (*e.g.*, Korotayev, Klimenko, and Proussakov 1999).

Chinese population dynamics during the Ming cycle are delineated below in Diagram 2.7:

Diagram 2.7. Estimated Population of China in millions: Ming Cycle (version 1)



NOTE: estimates of Zhao and Xie (1988: 539–40).

The official Ming census records give much lower figures, indicating that the population grew up to 60.5 million by 1393 and then fluctuated between a bit more than 50 million (1431 – 1435, 1487 – 1504) and 63–65 million (1486, 1513, 1542 – 1562); in 1602 it was 56.3 million, in 1620 – 1626 it was 51.7 million (*e.g.*, Durand 1960: 231–2).

There is a perfect consensus that the actual population of Ming China was much higher. What is more, this appears to have been clear to the Ming Chinese themselves:

"The official census records were hopelessly out of touch with demographic reality. The compiler of a Zhejiang gazetteer of 1575 insisted that the number of people off the official census registers in his county was three times the number on. A Fujian gazetteer of 1613 similarly dismissed the impression of demographic stagnation conveyed by the official statistics: 'The realm has enjoyed, for some two hundred years, an unbroken peace which is unparalleled in history,' the editor pointed out. 'During this period of recuperation and economic development the population should have multiplied several times since the beginning of the dynasty. It is impossible that the population should have remained stationary.' A Fujian contemporary agreed: 'During a period of 240 years when peace and plenty in general have reigned [and] people no longer know what war is like, population has grown so much that it is entirely without parallel in history.' Another official in 1614 guessed that the increase since 1368 had been fivefold. China's population did not grow between 1368 and 1614 by a factor of five, but it certainly more than doubled" (Brook 1998: 62).

Thus, nobody appears to doubt that the actual population of Ming China was much higher than it is indicated by the Ming census (what is more, many Ming Chinese do not seem to have had doubts about this either); however, there is no consensus at all as regards just how much higher it was. In fact, the estimates by Zhao and Xie are among the lowest. Most experts suggest for the end of the Ming much higher figures: 150 million (Ho 1959: 264), 120–200 million (Perkins 1969: 16), 175 million (Brook 1998: 162), 200 million (Chao 1986: 89), or even 230–290 million (Heijdra 1998: 438–40; Mote 1999: 745).

As can be seen, Heijdra and Mote propose the most radical revision of the Ming census data, of the earlier estimates, and, in fact, of the population history of Late Imperial China in general. Indeed, their suggestions provide an entirely new vision of not only Ming, but also Qing population history. Heijdra (1994; 1998) who collected evidence for this revision, starts with re-estimation of population data for 1380, arriving at 85 instead of 60 million (Heijdra 1994: 52; 1998: 437); he then suggests that population growth rates tended to decrease from early Ming till late Qing. As regards the concrete estimates of population growth rates, Heijdra suggests three sets of figures ("low", "middle", and "high" hypotheses):

"The high hypothesis envisages a 0.6 percent increase in population per year from 1380 to 1500, 0.5 percent from 1500 to 1600, and 0.4 percent from 1600 to 1650 (from which could be subtracted losses through war and disasters, *although those are probably covered in the lower rate for the final fifty years*[8]). The middle hypothesis envisages growth rates of 0.5 percent, 0.4 percent, and 0.3 percent respectively. An implausibly low set of growth rates for the same three periods would be 0.4 percent, 0.3 percent, and 0.2 percent. The results of applying these figures are… revealing. The high hypothesis gives 175 million by 1500, 289 million for 1600, and 353 million for 1650. The last figure is almost equal to the official figure from the year 1812, which is perhaps the most reliable

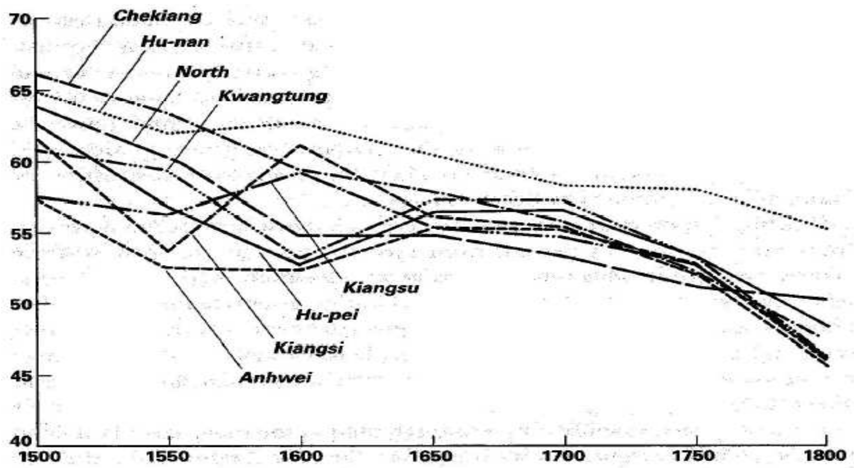
[8] The emphasis is ours – A.K., A.M., D.K.

official figure after 1393.[9] The middle hypothesis gives figures of 155, 231, and 268 million for the three dates, while the quite implausible[10] lower hypothesis gives 137, 185, and 204 million" (Heijdra 1998: 438).

As was mentioned above, this suggests a radical revision of not only Ming, but also Qing population history. For example, it implies the absence of separate Ming and Qing demographic cycles, suggesting their merging into one cycle (note that this was already suggested in 1990 by Kul'pin [p. 123]; hence, we may speak about the Kul'pin – Heijdra – Mote revision, though it was only Heijdra who provided any significant substantiation for this hypothesis).

Heijdra bases his revision mainly on the data (extracted from genealogical [*chia-p'u*] materials) on the life expectancy dynamics in Ming and Qing China, which he usefully summarizes in the following diagram (see Diagram 2.8):

Diagram 2.8. Regional Life Expectancy from 1500 to 1800 (= Fig. 9.3. from Heijdra 1998: 437).



NOTE: "The figures indicate the average age at death of the population already having reached the Chinese age of 15" (Heijdra 1998: 437).

However, let us study this diagram more attentively. Note first of all a very sharp and uniform decline of life expectancies in the 18th century (relatively slow in the first half of the 18th century [when, as we shall see below, according to conventional accounts the population growth was relatively slow], and very

[9] Note that this implies that in the 18th century (generally believed to be the period of the fastest population growth in the pre-20th century Chinese history) the population of China actually stagnated. As we shall see below, this hypothesis appears to be totally implausible – A.K., A.M., D.K.

[10] In fact, as we shall see below, these estimates are the most plausible (at least for the years 1500 and 1600) – A.K., A.M., D.K.

fast in the second half of this century when the population growth rate was especially high). In fact, this is entirely congruent with the data of other scholars (*e.g.*, with the materials of Liu 1995: 118–9, or Harrell and Pullum 1995: 148, who find in their 3 datasets life expectances at birth of 50–54 for the 17th century, 31–41 for the 18th century and just 25–28 for the years 1800 – 1874; see also, *e.g.*, Lavely and Wong 1998: 721). However, in conjunction with the data on the equally rapidly decreasing per capita acreage and consumption rates (*e.g.*, Chao 1986: 89, 218–9; Wang 1992: 40–5, 48, 50, 57–8, 63; Li 1992: 77; Wong and Perdue 1992: 133; Nefedov 2000b: 19, *etc.*), what this actually suggests is precisely a very rapid population growth.

Another salient feature of Heijdra's diagram is that though within both the Ming and (especially) Qing we observe rather explicit trends towards decline in life expectancies, the situation is not as evident during the Ming – Qing transition, when three out of eight sample populations show significant growth of life expectances, and two display significant slow down in their decline. The data of other scholars suggest that this trend was much more salient than could be seen in Heijdra's diagram (*e.g.*, Liu 1995: 118–9). Incidentally, Liu makes a very relevant observation:

"The low mortality rate reflected in these data recorded from the early years of a lineage should not be considered as representing the real situation of the time when cohorts were active, for the data were apparently biased by a tendency for those men who lived longer to become founders of lineages or lineage branches. In other words, a lineage would not have formed if its ancestors were all very short-lived" (Liu 1995: 119; see also Harrell and Pullum 1995: 148; Lavely and Wong 1998: 722–3; Lee and Feng 1999: 173).

Liu's correction, of course, suggests that the life expectances in Ming China were not as high as is indicated by the genealogical data. On the other hand, as during the Ming – Qing transition life expectancies tended to grow notwithstanding "Liu's effect", their actual growth must have been considerably higher than it is indicated by these data (especially, due to the strong bottleneck effect observed during massive depopulations). This is actually very congruent with the data indicating the decline of the per capita acreage, and the growth of per capita consumption observed in the early Qing period as compared with late Ming, thus confirming conventional accounts of a rather significant population decline during the Ming – Qing transition (*e.g.*, Shang Yue 1959: 515; Chao 1986: 89, 218; Wang 1992: 40, 48, 50; Nefedov 2000b: 14).[11]

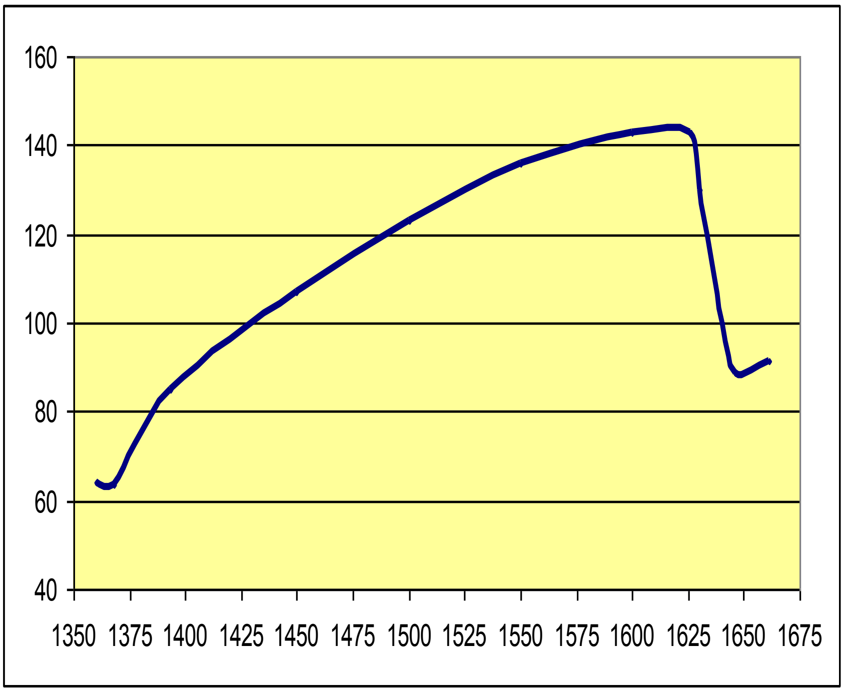
An improbable feature of Heijdra's reconstruction is his assumption that the population can grow at a rate of say 0.6% a year for 120 years. In fact wherever we have more or less reliable population figures, we do not find anything like this. In agrarian society within fifty years such population growth leads to diminishing of per capita resources, after which population growth slows down;

[11] For additional critique of the Kul'pin – Heijdra – Mote revision see Marks 2002.

then either solutions to resource problems (through some innovations) are found and population growth rate increases, or (more frequently) such solutions are not found (or are not adequate), and population growth further declines (sometimes below zero).

On the other hand, the evidence produced by Telford (1995: 69) suggests that the population growth rates experienced a sharp decline to close to zero levels by the end of the Ming period, and to negative values during the Ming – Qing transition. Assuming Heijdra's estimation of Chinese population for the year 1380, initial growth rate 0.4 and decline of population growth as 0.1 percent every 50 years we would get the following picture of the Ming population dynamics (see Diagram 2.9):

Diagram 2.9. Estimated Population of China in millions: Ming Cycle (version 2)

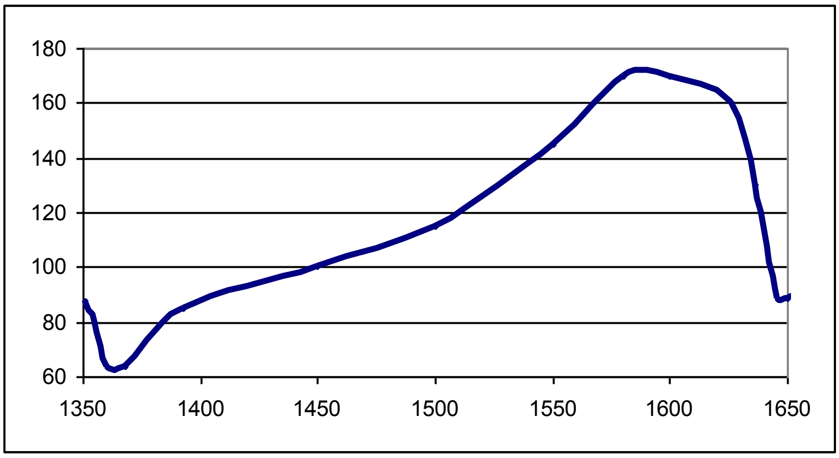


These estimates, perhaps, should be regarded as rather conservative. Of course, there do not seem to be sufficient grounds to rule out the possibility that the initial population growth rate was higher than suggested (and, hence, that by 1600 the Chinese population reached some figure between 150 and 200 million).

In general the estimates suggesting that the population during the Ming cycle exceeded significantly the level achieved during the Sung cycle look quite plausible against the background of the very large number of the carrying capacity enhancing innovations evidenced for the Ming period, from the introduction of some New World crops to the use of new fertilizers and increasing agricultural labor intensification (Ho 1955; Ho 1959: 172, 179, 183–4; Perkins 1969: 48–51; Bray 1984: 294–5, 526, 600–1; Chao 1986: 195; Twitchett and Mote 1998: 4–5; Heijdra 1998: 517, 519–23, Mote 1999: 749–50). Due to a high degree of unreliability of the pre-1741 Qing statistics (*e.g.* Ho, 1959: 24–35; Durand 1960: 234–8) the population estimates for Early Qin period vary greatly (*e.g.*, Ho, 1959: 24–35; Durand 1960: 234–8; Perkins 1969: 209; Peterson 2002: 5; Rowe 2002: 475, *etc.*); thus, the population of China well might have declined during the Ming – Qing transition to a level considerably over the one indicated in the diagram above. Note that this would not still affect the general shape of the Ming population dynamics.

However, it cannot be excluded that this shape was more like the Sung one – with two periods of relatively fast population growth (at the beginning of the cycle, and in the 16th century, with the second decline of this growth towards its end [as is suggested by data mentioned, *e.g.*, by Skinner 1985: 274–9; Shepherd 1988: 416], see Diagram 2.10):

Diagram 2.10. Estimated Population of China in millions: Ming Cycle (version 3)



There is extensive historical evidence for a rather long period of political instability and internal warfare during the Ming – Qing transition (Simonovskaja 1966; Atwell 1988: 603–40; Struve 1988; Dennerline 2002; Spence 2002: 120–150; Nepomnin 2005).

Chinese population dynamics during the Qing cycle are delineated below in Diagram 2.11:

Diagram 2.11. Population of China in millions: Qing Cycle

NOTE: estimates of Zhao and Xie (1988: 539–40).

Though there is considerable disagreement as regards exact figures for Chinese population, especially for the pre-1741 period, there is a very high degree of agreement as regards the general features of the Qing population dynamics: a rather fast growth in the 18th century, followed by a very significant slow down of population growth during the pre-collapse phase of the cycle (Ho 1959: 36–64; Durand 1960: 234–44; Perkins 1969: 202–9; Lavely and Wong 1998: 717–20; Nefedov 2000b; Myers and Wang 2002: 571; Rowe 2002: 475). The only contesting view is suggested by the Heijdra – Mote revision, which has been shown above to be untenable.

The population growth during the Qing cycle was sustained by a very considerable number of carrying capacity enhancing innovations (to a considerable extent supported and stimulated by the state), *e.g.*, the continuing introduction and wide diffusion of the New World crops, development of new varieties of previously known cultivated plants, agricultural labor intensification, land reclamation *etc.* (Ho 1955; Ho 1959: 173–4, 180, 185–9; Lee 1982; Bray 1984: 452, 601; Perkins 1969: 39–40; Dikarev 1991: 69–70; Fairbank 1992: 169; Lavely and Wong 1998: 725–6; Lee and Wang 1999: 37–40; Mote 1999: 750, 942; Nefedov 2000b: 17; Myers and Wang 2002: 599, 634–6; Rowe 2002: 479; Zelin 2002: 216–8). As a result of these innovations the carrying capacity of land during this cycle was raised to a radically new level.

The main revision here has been proposed by Lee, Feng, Lavely, Wong, and Campbell (Lee and Campbell 1997; Lavely and Wong 1998; Lee and Feng 1999, *etc.*), who deny altogether any demographic cycle dynamics during the Qing period, as they deny the decline of consumption levels, life expectancies *etc.*, predicted by demographic cycle models. However, the evidence that they present in support of this revision is not convincing. First of all, they dismiss too easily the massive evidence which has accumulated, by now, in support of the decline of the consumption rates, living standards, life expectancies *etc.* during the Qing cycle. Thus, the massive evidenced compiled by Chao Kang (1986: 193–220), which shows a dramatic decline in real wages during the Qing cycle, is dismissed outright by Lavely and Wang (1998: 731) as "hazardously thin", and is just not mentioned by Lee and Feng (1999).

However, as we shall see below, it is the evidence produced by the "revisionists" in support of their revision which is really "hazardously thin", especially in comparison with the massive and representative dataset compiled by Chao Kang. The above mentioned massive evidence for the very significant decline of the life expectancies during the Qing cycle compiled on the basis of genealogical data is dismissed in the following way alluding to what we called above "Liu's effect":

"Harrell and Pullum [1995: 148] themselves acknowledge these problems [with genealogical data – A.K., A.M., D.K.]: 'The apparent decline over time in the expectation of life in each genealogy is so great that it must be regarded as spurious. It is likely that in the seventeenth century, the chance that an individual would be included in the genealogy was positively related to that individual's longevity' " (Lee and Wang 1999: 173; a fairly similar argument is made by Lavely and Wong 1998: 722–3).

Lee and Wang do not appear to have understood what Harrell and Pullum meant. In fact, they do not imply that their data cannot be considered as rather firm evidence for a considerable decline of life expectancies in respective populations. They only mean that the decline in life expectancies might have been somewhat smaller than is suggested by their data, but in no way do they imply that a considerable decline of life expectancies did not occur at all. In fact as has been shown by Liu (1995: 119), "Liu's effect" is really strong only for very early periods (15th and especially 14th centuries), whereas "from the 1498 – 1557 cohorts on, as number of observations became large enough and the distribution of deaths covered almost every age group, the bias toward high age at death seems to have diminished". Indeed, as we saw above, Liu's effect fails to eliminate totally the trend towards the increase in life expectancies during the Ming – Qing transition predicted by demographic cycle models. Still, as is suggested by Harrell and Pullum, Liu's effect may still be felt in the 17th century data. However, the influence of this effect in the 18th century (and especially, the second half of the eighteenth century) must be negligible. However, this period of the most rapid population growth is precisely the period for which the genealogical data indicate the most rapid decline in life expectancies (see above Diagram 2.8 and comments to it).

On the other hand, for the earliest phases of the Qing demographic cycle, when the Liu's effect must have been greatest within the Qing period (but when the population growth rate was relatively low, and hence according to the demographic cycle model one does not have to expect significant declines in life expectancies), the genealogical data do indicate only rather small declines in life expectancies. All this, of course, suggests that the decline in life expectancies indicated by genealogical data for the Qing period evidences first of all actual decline (caused by demographic cycle mechanisms), and is accounted for to only a rather small degree by Liu's effect.

However, what positive evidence do the "revisionists" produce in support for their claim that during the Qing cycle there was no decline in consumption rates, living standards and life expectancies of commoner population? To start with, Lee and Wang (1999) present considerable amounts of convincing evidence showing the growth of per capita grain production, productivity of labor, stature, life expectancy, decline of mortality *etc.* in China. Yet, all these data refer to the 20th century.[12] Such evidence for Qing China is "hazardously thin".

On the one hand, here the "revisionists" rely to a disproportionate extent on the data referring to the Qing elites, first of all, the Qing imperial lineage. In fact, they showed quite persuasively that the life of the Qing elites was much better than the one of the commoners (actually, who would doubt this?[13]) and

[12] In fact, it demonstrates rather convincingly that in the second half of the 20th century China managed to escape quite successfully from the "Malthusian trap".

[13] In fact, it was earlier already shown by Telford (1990) that the Qing (and not only Qing) elites lived longer than commoners.

tended to improve: their life expectancies grew sharply in the 18th century (Lee, Wang, and Campbell 1994: 401; Lavely and Wong 1998: 723), health care improved and child mortality declined (Lee, Wang, and Campbell 1994; Lee and Wang 1999: 46–7).

Of course, this tells us nothing about such trends among the commoner population. For the growth of labor productivity in Qing China the "revisionists" rely solely on the Li Bozhong (1998) study (Lee and Wang 1999: 31). However, Li Bozhong's data only refer to the Lower Yangzi area, and have been shown to be totally unreliable and misinterpreted (Huang 2002).

As regards the data on increasing food consumption per capita in Qing China, it is derived mainly from late imperial agricultural handbooks, which indicate that "whereas an ordinary farm laborer in the sixteenth century was provided with meat 10 days a month *during the busy season* (our emphasis – A.K., A.M., D.K.), this allotment increased to 15 days a month in the seventeenth century and to 20 in the nineteenth" (Lee and Wang 1999: 34). Note, however, that these handbooks were compiled by a sort of exemplary literati – farm owners, and in no way reflect the general situation (Heijdra 1994: 308–10). Note also that handbooks indicate not an increase in real wages, but rather in increase in food provided by farmer owners to feed their workers in the field *during the busy season.* One wonders if this was not designed to compensate the decreasing real wages (Chao 1986: 193–220) and to avoid the workers' productivity of labor falling below a critical level during hard work at harvest time.

The other source used by the "revisionists" to prove the increase of living standards of commoner population in Qing China is the study by Pomeranz (2000) comparing living standards of the population of the most developed area of Qing China, the Lower Yangzi, and Western Europe in the second half of the 18th century (Lee and Wang 1999: 34–5). As has been shown by Huang (2002) Pomeranz significantly overestimates the living standards of the Yangzi Delta commoner population.[14] However, this is not the most important point.

Pomeranz may still be mostly right in his basic argument that the living standards in the most developed part of Qing China in the second half of the 18th century might not have been so much lower than the contemporary European ones. Yet, this study is simply not relevant for the revision of Qing demographic history. The main problem with it here is that it is synchronic rather than diachronic, and hence cannot be used to support or reject any hypothesis on the demographic *dynamics.* What would be relevant here is the comparison

[14] Paradoxically, Rowe (2002: 501) uses Lee and Wang's data to criticize (in an entirely appropriate way) the assertion that the standard of living in late 18th century China was not lower than in contemporary Western Europe: "Their remain, however, reasons for caution in our appreciation of the mid-Ch'ing as an era of plenty. Lee and Wang themselves, while arguing that rising nutritional levels support their thesis that prosperity bred relaxed population controls, admit that the pronouncedly lower stature of the pre-Modern Chinese in comparison with contemporary Europeans indicates lower living standards".

between the living standards of this area's population, say, in 1750 – 1770 and 1820 – 1840. If such data show an increase in living standards during this period, this could be considered as some support for the "revisionist" hypothesis. However, such a verification/falsification of a dynamic hypothesis simply cannot be done on the basis of synchronic studies.

In general, the "revisionists" appear to have failed to produce convincing evidence in support of their hypothesis, and to disregard evidence to the contrary; thus, their hypothesis has to be rejected (for additional critique of the Lee *et al.* revision see, *e.g.*, Wolf 2001; Huang 2002).

Note that the historical demographic data of Lee *et al.* on Han banner population in Liaoning (for 1774 – 1873) do not contradict conventional accounts, though this is claimed by the "revisionists". For example, Lavely and Wong claim that "although there are some fluctuations [in the Liaoning time series] over the four decades for which Lee and his associates present data, there is no discernable trend" (1998: 723 with reference to Lee, Campbell, and Anthony 1995: 177, Figs. 7.1 and 7.2).

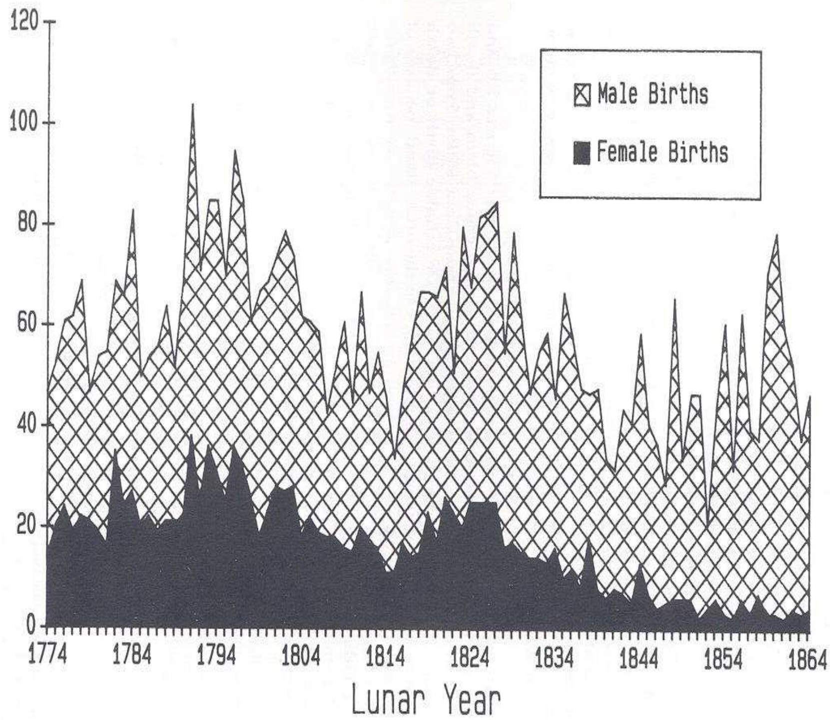
However, a careful inspection of these two diagrams does reveal a significant (though not very strong) trend towards increasing mortality and decreasing life expectancies (with the lowest mortality rates at the beginning of the period under consideration, in 1772 – 1780, and with the lowest life expectancies at the end of the same period, in 1819 – 1840). In fact, Lavely and Wong themselves notice that in their sample life expectancy at birth in 1798 – 1801 was 43 years, but in 1837 – 1840 it was just 33 (1998: 721, Table 3A, where they display other data confirming the presence of a general trend towards declining life expectancies within the Qing cycle[15]).

An important contribution of Lee *et al.* was that they demonstrated how important female infanticide was as a factor of population dynamics in pre-Modern and early Modern China. Though the importance of this factor was well known at least since the pioneer work of Fei Hsiao-t'ung (1939: 22, 33–4; see also *e.g.* Ho 1959: 58–62, 274–5), Lee *et alii*'s findings suggest that the decline of population growth rates towards the end of the Qing cycle might be accounted for by the growth of female infanticide to a larger extent than by the growth of adult mortality. Indeed, their findings suggest an enormous growth of the female infanticide rates in the latest phases of this cycle[16] (see, *e.g.*, Diagram 2.12):

[15] The only exception they mention belongs squarely to that very type of exceptions, which only confirm the rule – this is just the Qing imperial lineage (Lavely and Wong 1998: 721).

[16] We would also like to note their very interesting mathematical specification of the effects of female infanticide on population growth rate (Lavely and Wong 1998: 736–8). We believe that in the future this model should be definitely taken into account for development of advanced models of demographic cycles.

Diagram 2.12. Crude Birth Rates in Daoyi, 1774 – 1864
(per 1,000 married women aged 15–45)
(Lee, Campbell, and Tan 1992: 164, Fig. 5.5)



Another important finding of Lee *et al.* was their discovery of rather strong and significant correlations between the staple prices and female infanticide rates (*e.g.*, Lee, Campbell, and Tan 1992: 158–75). This of course suggests that the growth of female infanticide was caused by the declining living standards, as was already noticed, for example, by Mann: "The … decline in population growth during the nineteenth century owed much to a rise in female infanticide, itself a direct response to declining economic opportunity" (Mann 2002: 451).

Thus, we believe Lee *et alii*'s data do not prove the absence of demographic cycles in Chinese history; rather they enrich our knowledge of concrete mechanisms of functioning of those cycles.

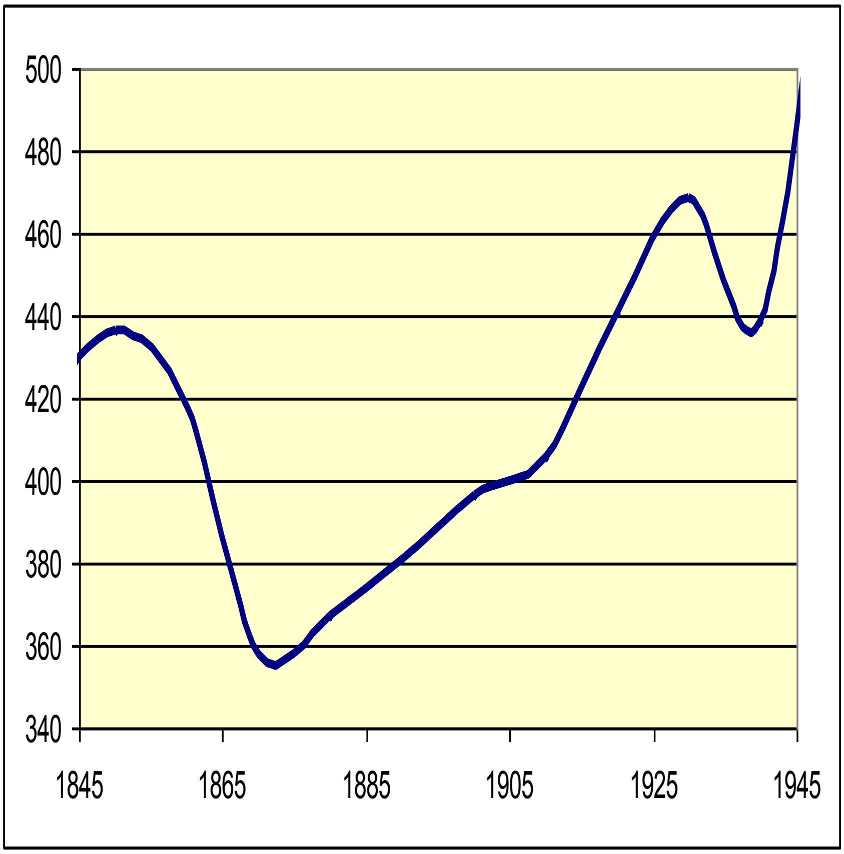
Note, for example, that female infanticide was not just an innocuous "preventive check":

"Recent research in Chinese legal history suggests that the same subsistence pressures behind female infanticide led to widespread selling of women and girls… Investigations into case records show that the buying and selling of women were so widespread that litigation stemming from such transactions accounted for perhaps 10 percent of all civil cases handled by the local courts… Another related social phenomenon was the rise of an unmarried "rogue male" population, a result both of poverty (because the men could not afford to get married) and of the imbalance in sex ratios that followed from female infanticide. Recent research shows that this symptom of the mounting social crisis led, among other things, to large changes in Qing legislation vis-à-vis illicit sex… Even more telling, perhaps, is the host of new legislation targeting specifically the 'baresticks' single males (*guanggun*) and related 'criminal sticks' of bandits (*guntu, feitu*), clearly a major social problem in the eyes of the authorities of the time. As with the mounting problem of trafficking in women and girls, the Qing state promulgated no fewer than eighteen substatutes to deal with the new social problem" (Huang 2002: 528–9; see also, *e.g.*, Hudson and Den Boer 2002).

There is considerable evidence on the population decline and significant period of political instability and internal warfare after 1851 (Iljushechkin 1967; Perkins 1969: 204; Larin 1986; Kuhn 1978; Liu 1978; Nepomnin 2005 *etc.*). In fact, the extent of the late Qing demographic collapse might have been even higher than is indicated in Diagram 58: "Cao Shuji's new research, based on exhaustive use of local gazetteers and prefecture-by-prefecture reconstructions of population totals and changes, suggests a total death toll from these devastations between the years 1851 and 1877 of a whopping 118 million" (Huang 2002: 528). The Qing demographic cycle might look exceptional in sense that the demographic collapse at its end did not lead to the immediate fall of the Qing dynasty. However, the same is observed for the early T'ang cycle. And here again it may be argued that the demographic collapse was "the beginning of the end" of the dynasty.

Finally, one wonders if we cannot speak about one more demographic cycle in the Chinese history, the "Republican" one, with the late 1930s demographic collapse resulting finally in the "Mandate of Heaven" changing its hands once again (see Diagram 2.13):

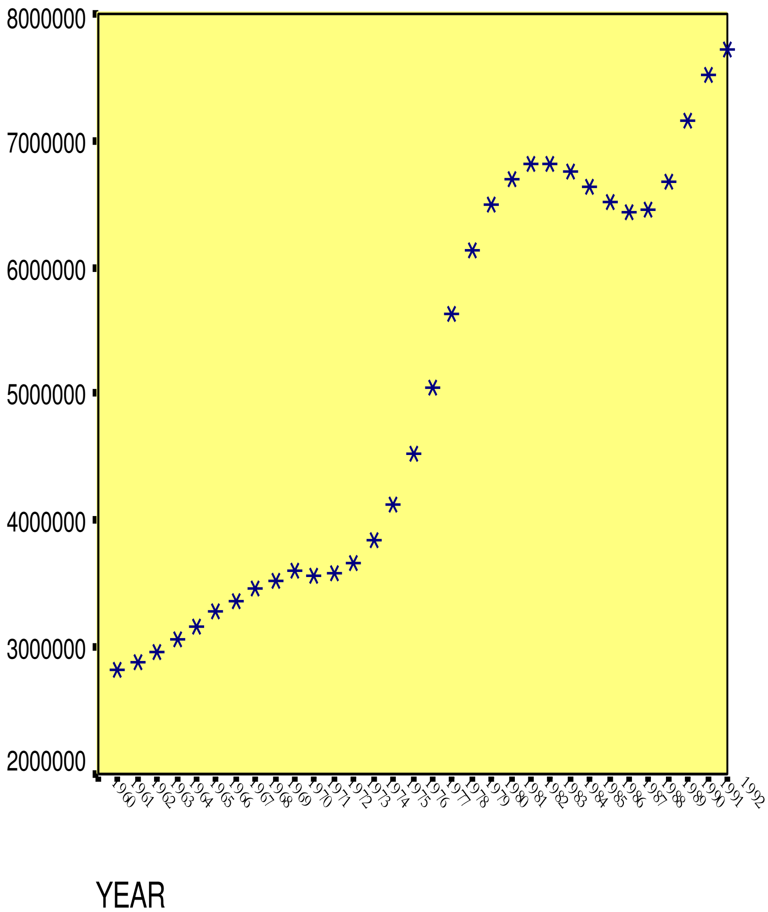
Diagram 2.13. Population of China in millions: "Republican" Cycle?



NOTE: estimates of Zhao and Xie (1988: 543).

Note that the famous Buck's Chinese Farm Survey (Buck 1937) indicates the presence of all the pre-collapse symptoms. For example, the Princeton reanalysis of this survey found life expectancy at birth in the early 1930s Chinese countryside being as low as 24 years (Barclay *et al.* 1976). However, the data on "Republican" demographic cycle could scarcely be used for the reconstruction of pre-Modern population dynamic patterns, as it seems to be closer to Modern Third World demographic cycles, characterized by relatively short durations, very short periods of pre-collapse slow-downs, the fast demographic growth restarting almost immediately after the demographic collapse, *etc.* (see, *e.g.*, Korotayev and Khaltourina 2006: Chapters 7–8 and Diagram 2.14):

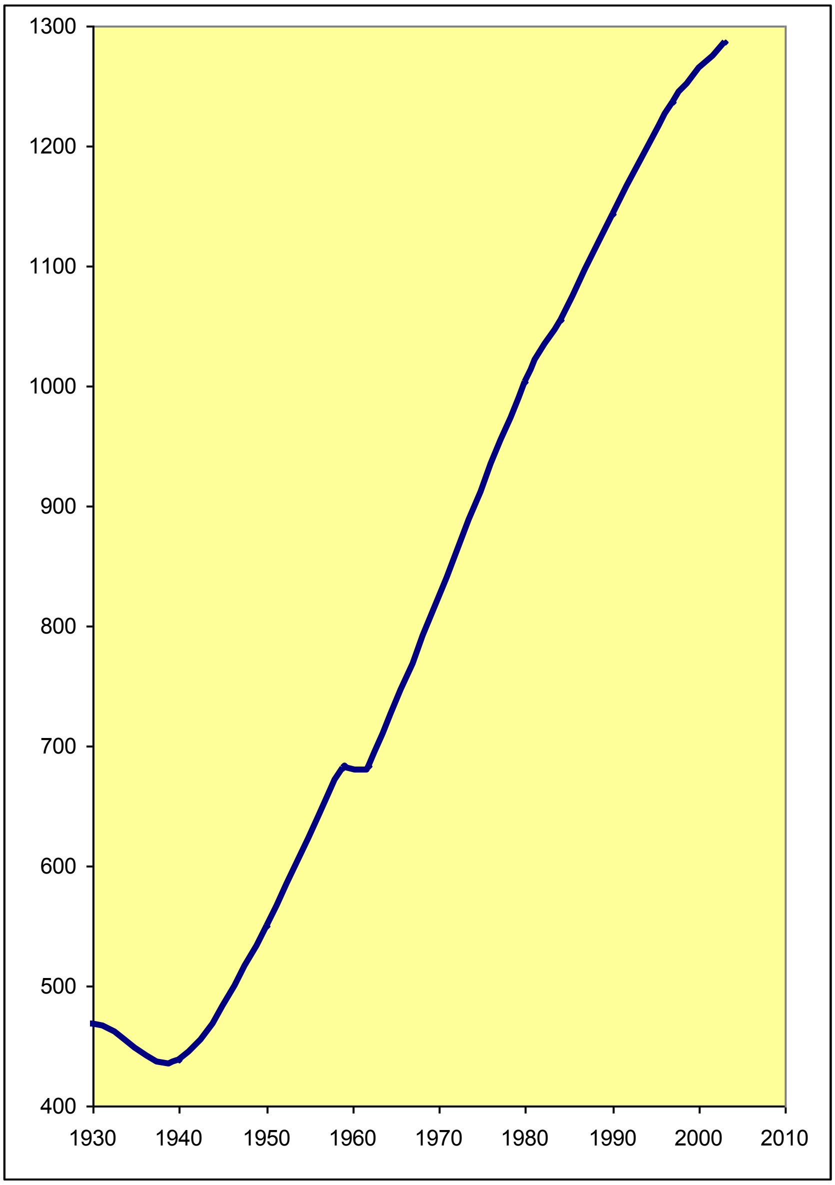
Diagram 2.14. Somalian Political-Demographic Cycles (1960 – 1990)



Data source: World Bank 2005.

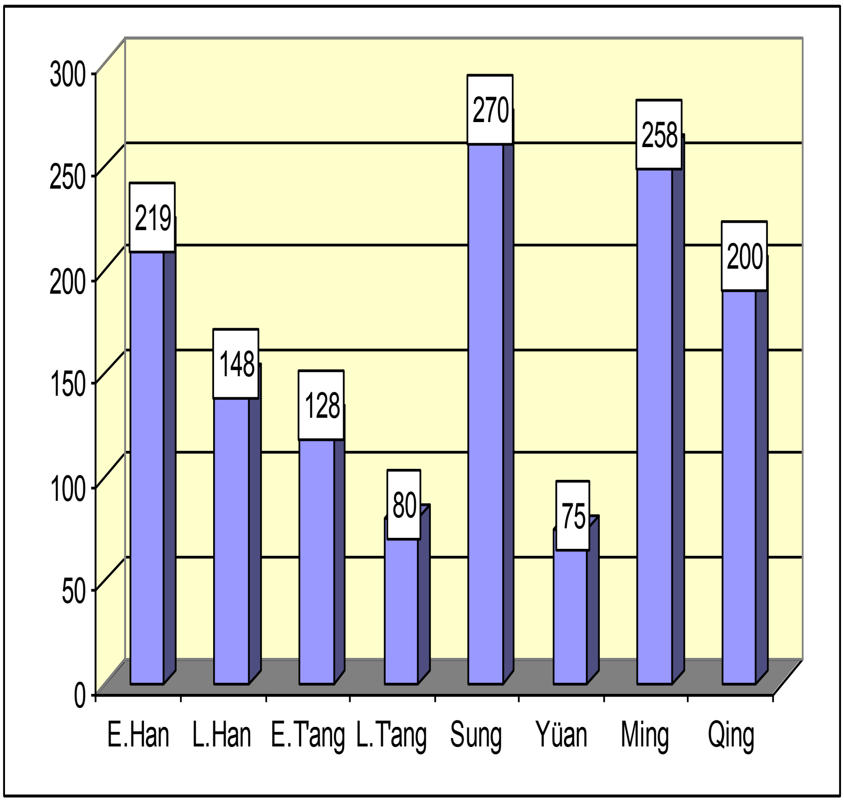
Finally, though the population dynamics curve for "Communist" China (see Diagram 2.15) bears some superficial resemblance to previous demographic cycles, we have no grounds to speak about a demographic cycle in this case, as the decline of population growth took place against the background of rising living standard and life expectancy, as well as decreasing mortality, and was accounted for by decreasing birth rates (*e.g.* Lee and Wang 1999):

Diagram 2.15. Population of China in millions: Communist/Postcommunist Pseudocycle



Let us summarize some observations on the patterns of demographic cycles in pre-Modern China. First of all, note that at first glance the data do not reveal any significant trend to the lengthening (or shortening) of the demographic cycle durations (see Diagram 2.16):

Diagram 2.16. Duration of Demographic Cycles



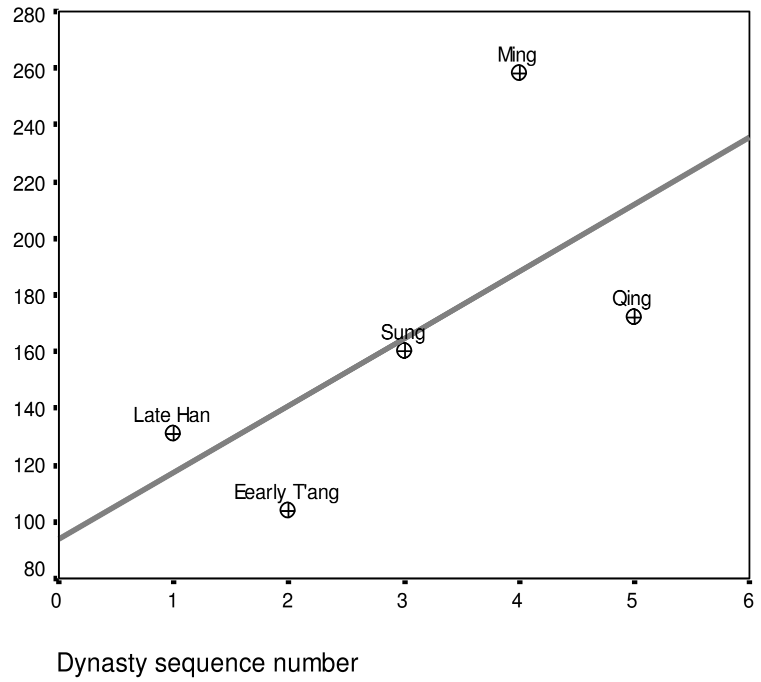
NOTE: Rho = .095, p = .82. Incidentally, as we see, a typical duration of a Chinese demographic cycle is 150–250 years.

However, we find a definite trend towards the increase in the growth phase lengths if we consider only the cycles for which direct historical demographic evidence is available, and omit the Late T'ang period[17], as well as the evidently prematurely collapsed Yüan dynasty (see Table 2.1 and Diagram 2.17):

[17] As it is not entirely clear if the Late T'ang period should not be regarded as a part of the T'ang – Sung intercycle rather than a separate cycle; see above.

Table 2.1 and
Diagram 2.17. Growth Phase Lengths of Chinese Political-Demographic Cycles

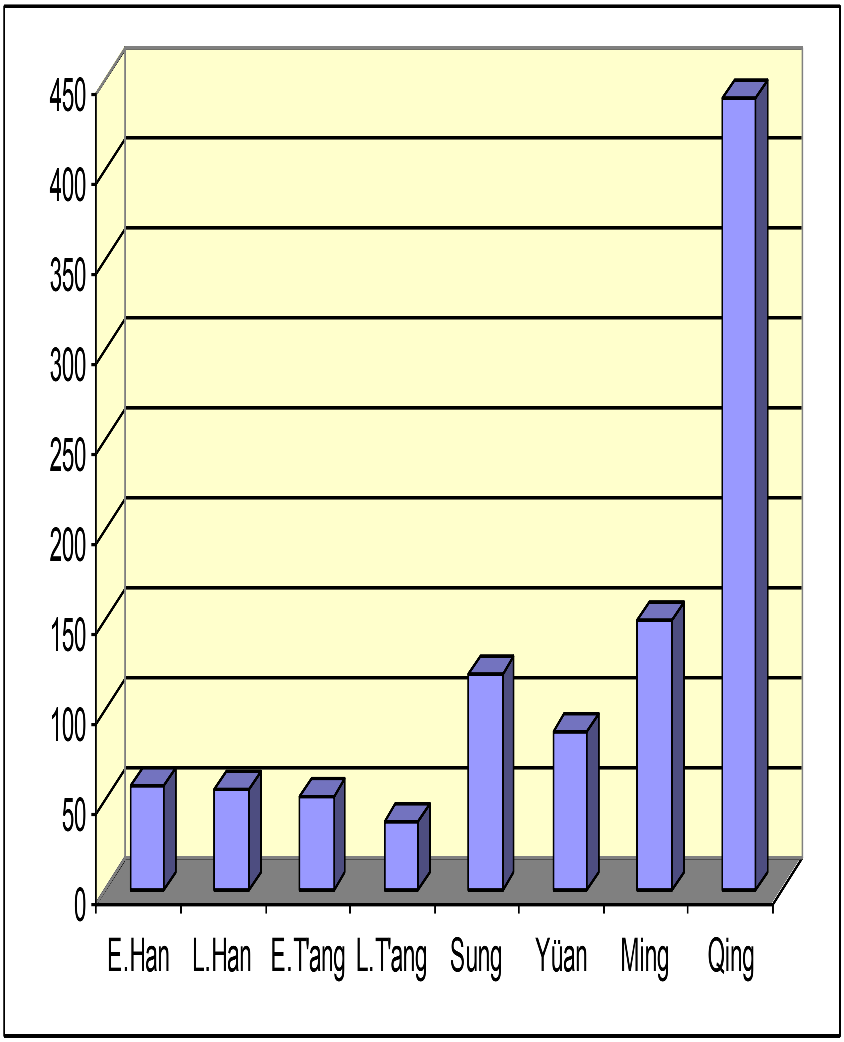
Cycle Name	Beginning of growth phase (CE)	Beginning of demographic collapse (CE)	Growth phase length (years)
East (Late) Han Cycle	57	188	131
(Early) T'ang Cycle	650	754	104
Sung Cycle	960	1120	160
Ming Cycle	1368	1626	258
Qing Cycle	1680	1852	172



NOTE: Rho = .8, p = .05 (1-tailed). The reasons for the use of a 1-tailed significance test here will become apparent in the next chapter.

On the other hand, it is hardly surprising that the data indicate an unequivocal upward trend for the maximum population numbers reached within a cycle (see Diagram 2.18):

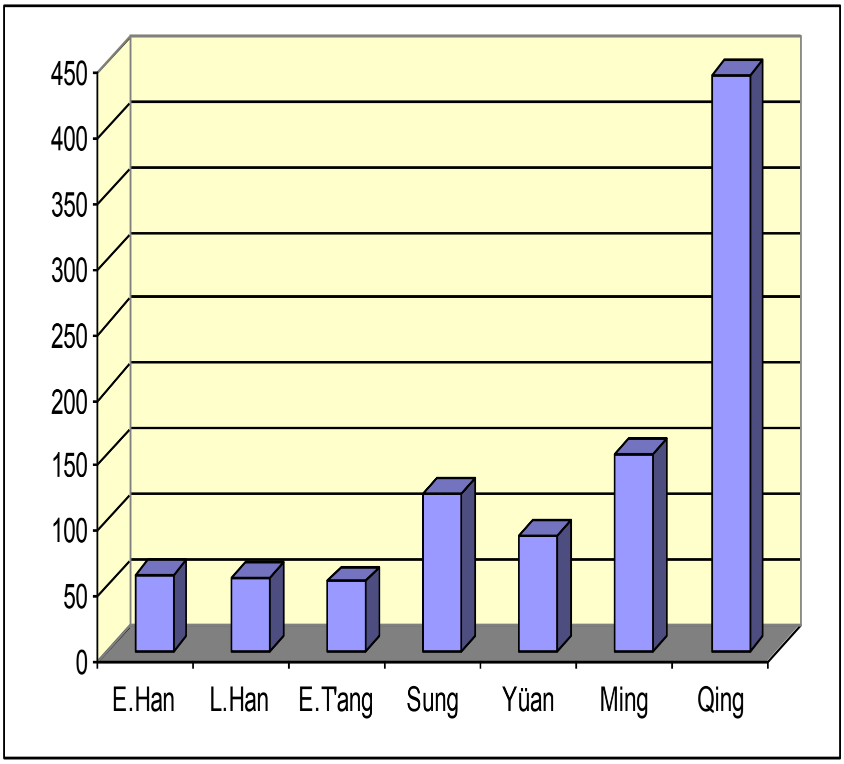
Diagram 2.18. Highest Population Numbers Reached during Dynastic Cycles (version 1).



NOTE: Rho = .74, p = .037.

If we use estimates of Zhao and Xie (1988: 536–7) for Han and Early T'ang, and consider the Late T'ang period as a part of an intercycle, rather than as a separate cycle, the trend will be even more pronounced (Diagram 2.19):

Diagram 2.19. Highest Population Numbers Reached during Dynastic Cycles (version 2).

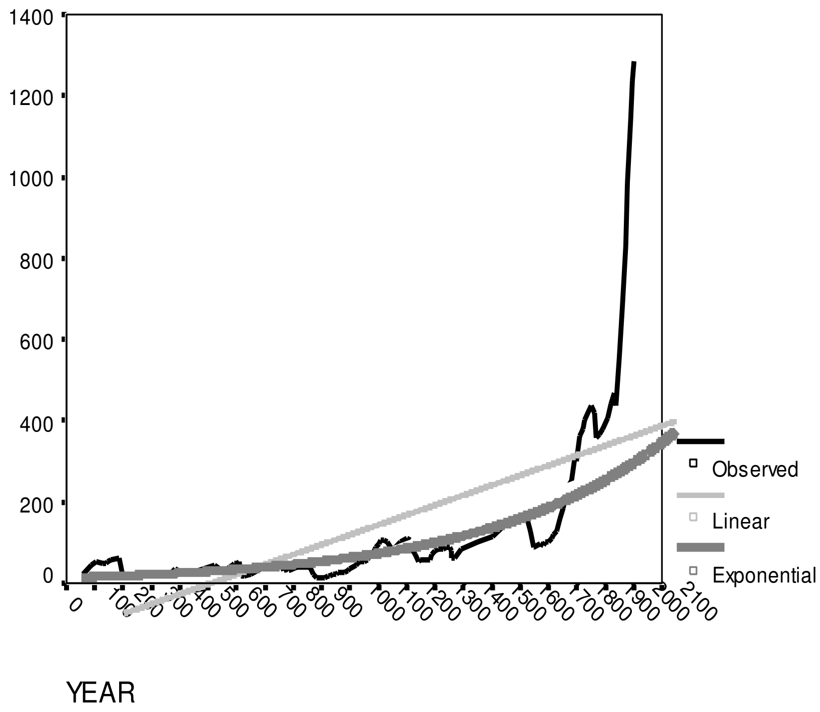


NOTE: Rho = .93, p = .003.

What kind of trend do we observe here? Linear regression suggests a statistically significant ($p < 0.001$) relationship with $R^2 = 0.398$.[18] Exponential regression produces an even stronger result with $R^2 = 0.685$ ($p < 0.001$); see Diagram 2.20:

[18] All regressions for pre-industrial and industrial periods combined were calculated for years 57 – 2003.

Diagram 2.20. Curve Estimations for Chinese Population Dynamics, millions, 57 – 2003 CE (linear and exponential models)

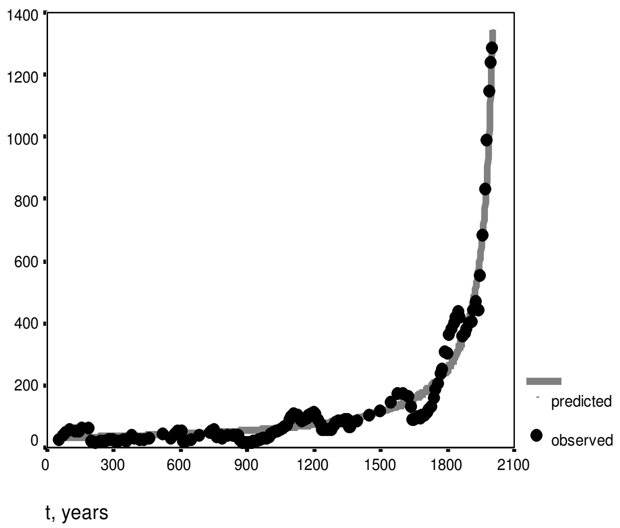


NOTES: The thin black line corresponds to the observed population dynamics surveyed in this chapter. *Linear regression*: $R = 0.631$, $R^2 = 0.398$, $p < 0.001$. The respective best-fit thin light grey line has been generated by the following equation: $N_t = 0.2436t - 124.25$. *Exponential regression*: $R = 0.828$, $R^2 = 0.685$, $p < 0.001$. The respective best-fit thick dark grey line has been generated by the following equation: $13.3575 \times e^{0,0015t}$. The best-fit values of parameters have been calculated with the least squares method.

However, a simple hyperbolic growth model produces a much better fit with the observed data ($R^2 = 0.968$, $p << 0.001$[19]), see Diagram 2.21:

[19] In fact, to be exact, statistical significance of the fit in this case reaches an astronomical level of 1.67×10^{-19}.

Diagram 2.21. Population Dynamics of China (57 – 2003 CE), millions, correlation between the observed values and the ones predicted by a hyperbolic growth model



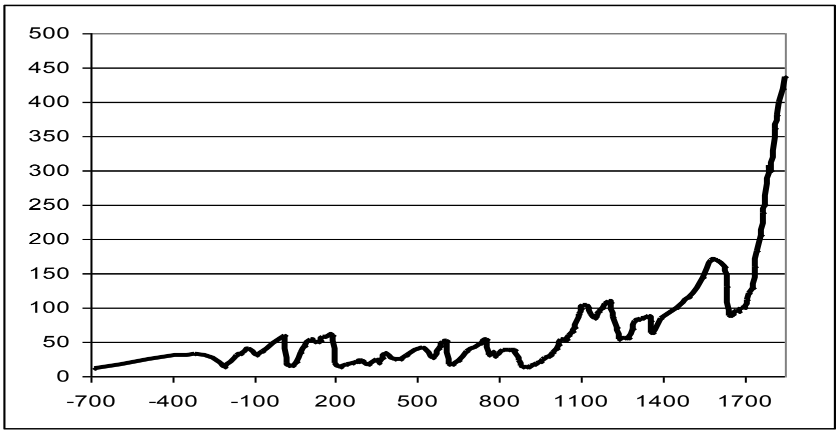
NOTE: R = 0.984, R^2 = 0.968, $p = 1.7 \times 10^{-19}$. The black markers correspond to empirical estimates surveyed in this chapter. The grey solid line has been generated by the following equation:

$$N_t = \frac{63150.376}{2050 - t}.$$

The best-fit values of parameters C (63150.376) and t_0 (2050) have been calculated with the least squares method.

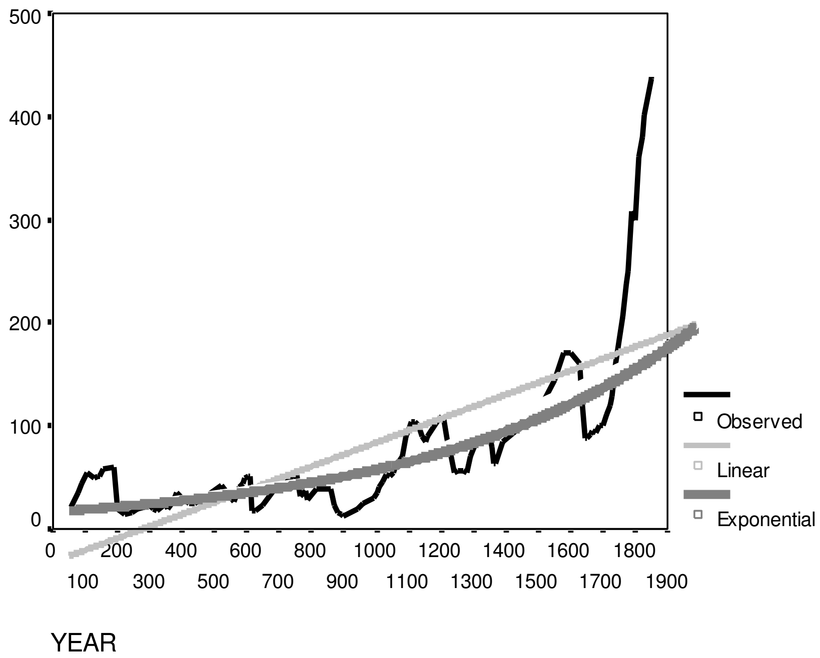
Yet, even if we consider only the pre-Modern history of China (up to 1850), we will still find the hyperbolic growth trend for this part of Chinese history too (see Diagrams 1.22–3):

Diagram 2.22. Population Dynamics of Pre-Modern China (700 BCE – 1850 CE)



What kind of trend do we observe here? Linear regression again suggests a statistically significant (p < 0.001) relationship with R^2 = 0.469. Exponential regression again produces an even stronger result with R^2 = 0.593 (p < 0.001); see Diagram 2.23:

Diagram 2.23. Curve Estimations for Pre-Modern Chinese Population Dynamics, millions, 57 – 1850 CE (linear and exponential models)

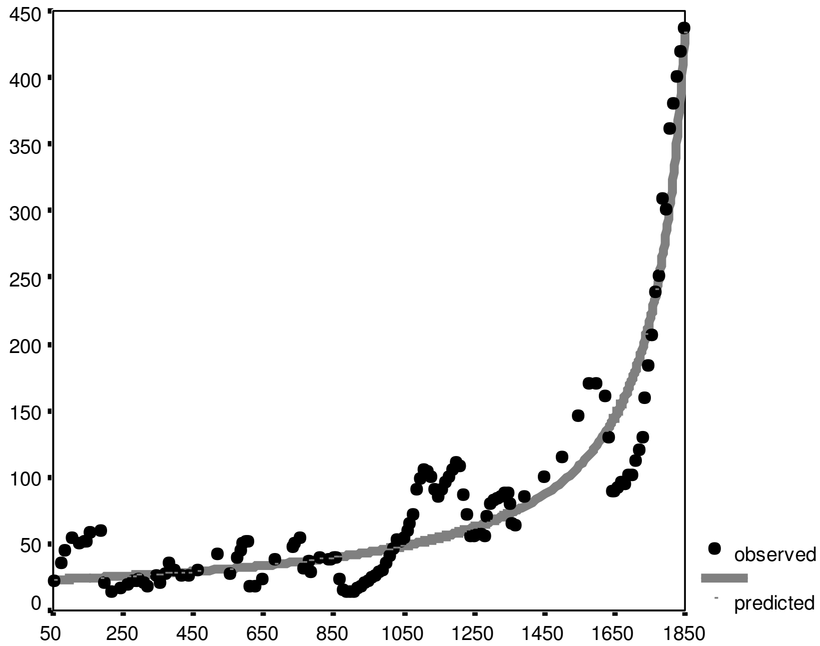


NOTES: The thin black line corresponds to the observed population dynamics surveyed in this chapter. *Linear regression*: R = 0.689, R^2 = 0.469, p < 0.001. The respective best-fit thin light grey line has been generated by the following equation: $N_t = 0.1098t - 27.97$. *Exponential regression*: R = 0.770, R^2 = 0.593, p < 0.001. The respective best-fit thick dark grey line has been generated by the following equation: $16.9785 \times e^{0{,}0012t}$. The best-fit values of parameters have been calculated with the least squares method.

However, a simple hyperbolic growth model once more produces a much better fit with the observed data (R^2 = 0.884, p << 0.001[20]), see Diagram 2.24:

[20] To be exact, statistical significance of the fit in this case again reaches an astronomical level (2.8×10^{-19}).

Diagram 2.24. Population Dynamics of Pre-Modern China (57 – 1850 CE), millions, correlation between the observed values and the ones predicted by a hyperbolic growth model



NOTE: $R = 0.94$, $R^2 = 0.884$, $p = 2.8 \times 10^{-19}$. The black markers correspond to empirical estimates surveyed in this chapter. The grey solid line has been generated by the following equation:

$$N_t = \frac{33430.518}{1915 - t}.$$

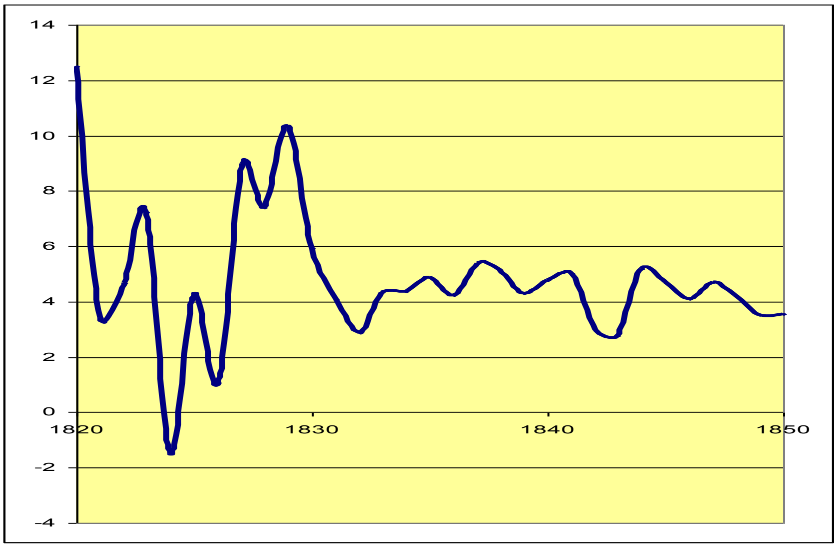
The best-fit values of parameters C (33430.518) and t_0 (1915) have been calculated with the least squares method.

Thus, the trend observed in the Chinese historical population dynamics (both for the whole Chinese history, and for its pre-industrial part) is not lineal; it is not even exponential, but is in fact just hyperbolic.

As was mentioned above, this trend is accounted for by the innovations in the raising of the carrying capacity of land. The most massive innovations of this kind took place during the Sung and Qing cycles, which accounts for their shapes being rather different from the rest of the cycles in that they include very strong "trend-creating" components.[21]

After detrending, a typical Chinese population cycle looks as follows: its dynamics are characterized by a relatively fast population growth at the initial phases of the cycle, followed by rather long periods (normally, of an order of a century, or even more) of a very slow and unsteady population growth rate. This is accompanied by increasing significant, but non-critical annual fluctuations in the annual growth (occasionally dropping to zero, or even negative values). These fluctuations are mostly caused by annual fluctuations in climatic conditions causing fluctuations in annual yields, and hence rises of population growth rates in good years, and their drops in lean years (accompanied by famines, minor epidemics, rebellions *etc.*). These fluctuations tended to be smoothed during the initial phases, when the countercrisis potential was at its peak, but tended to increase in magnitude during the pre-collapse phases, with decrease both in the effectiveness of functioning of relief sub-systems, and in average consumption levels. For example, Zhao and Xie (1988: 542) provide the following estimates of the annual population growth rates on the basis of the official Qing statistics for the pre-collapse decades (see Diagram 2.25):

Diagram 2.25. Annual Population Growth Rate Fluctuations in Late Qing China (1820 – 1850, in ‰)



[21] As was mentioned above, rather massive innovations in the raise of the carrying capacity of land appear to have taken place also during the Ming cycle, though this does not seem to be adequately reflected in the Ming population dynamics reconstructions described above.

There are considerable doubts about the accuracy of the data on those fluctuations (*e.g.*, Durand 1960), but they still seem to reflect some reality, as for this period we have much historical data on occasional famines poorly mitigated by relief systems whose effectiveness was very low at this phase, increasing severity of floods (caused by the decline of the effectiveness of the flood-preventing subsystem), rebellions *etc.* (*e.g.*, Mann Jones and Kuhn 1978).

Nefedov's model captures rather well this part of population dynamics; however, there are a few problems with it. Within this model after a relatively short initial period of rapid growth, population stagnates and fluctuates at the carrying capacity level. Yet, in none of the cases analyzed above do we observe exactly this. The closest fit to this model is found for the Eastern Han cycle (see Diagram 2.2), whose dynamics seem to have been overgeneralized by Nefedov. In fact, the point that 20–30 years after 105 CE the population registered by the Chinese census did not increase is accounted for, first of all (and this, incidentally, was acknowledged by Nefedov [1999e: 8] himself), by the lost of significant territories in the North-West by the Han state. Hence, the decrease of population registered by the census reflects, above all, the loss of control by the Han state over some of its territory (and population) rather than actual population decline.

Note that as Nefedov's (2004) own data suggest, after the territory controlled by the Eastern Han Empire had stabilized, the population growth resumed again. So actually, in the history of China the periods of fast population growth tended to be followed by periods of much slower growth (with considerable fluctuation), rather than population stagnation. Of course, this growth can be accounted for partly by carrying capacity enhancing innovations; but as our model suggests, some such growth could take place in the pre-final phases of a cycle even if the carrying capacity of land remained stable. The other problem with Nefedov's model is that within it fast population growth starts immediately after demographic collapse, whereas, as we saw above, in reality the periods of new fast population growth were always separated from demographic collapse by significant "intercycles", when the population growth is suppressed by continuing internal warfare.

The overall functional scheme of Pre-Modern Chinese demographic cycles, outlining most of the mechanisms of demographic collapse which we have found in the literature, is presented below in Diagram 2.26:

Diagram 2.26/1. Functional Scheme of a Pre-Industrial Chinese Demographic Cycle (pre-collapse and collapse phases) (Part 1)

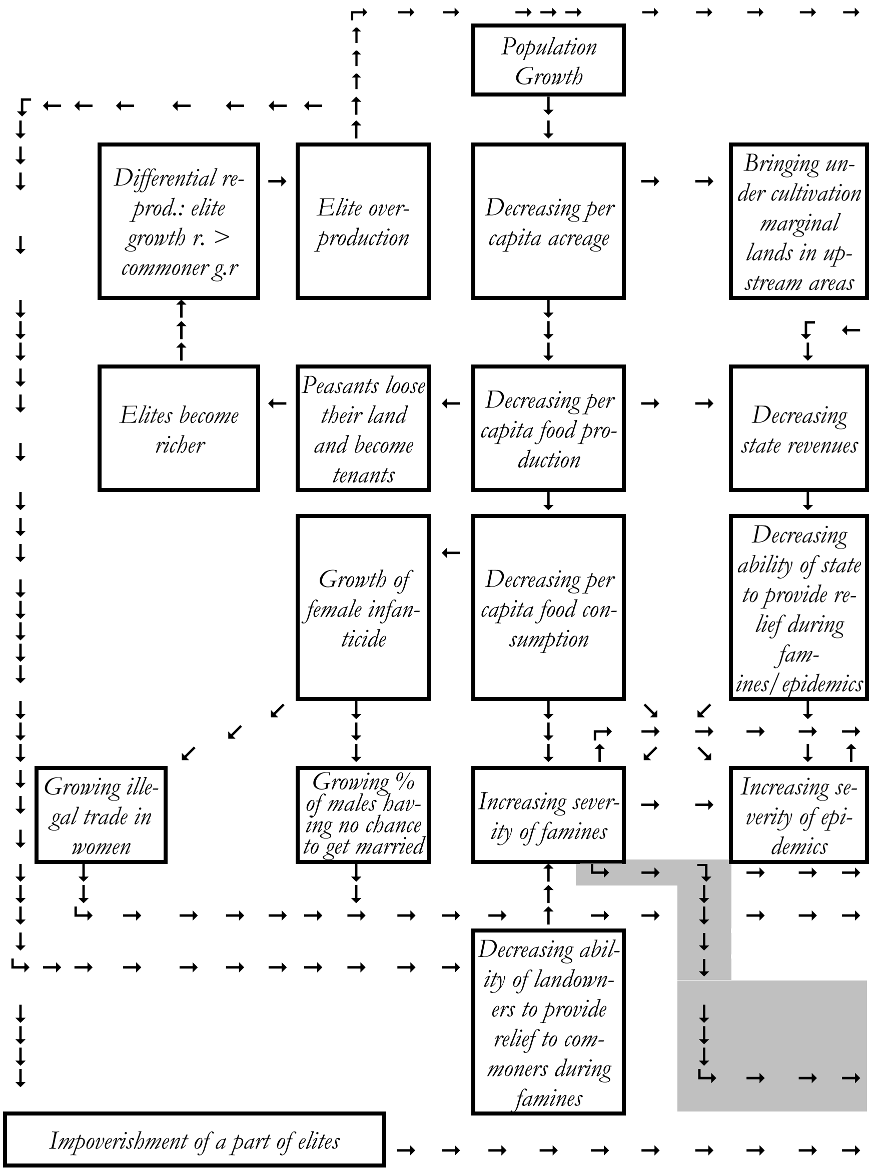
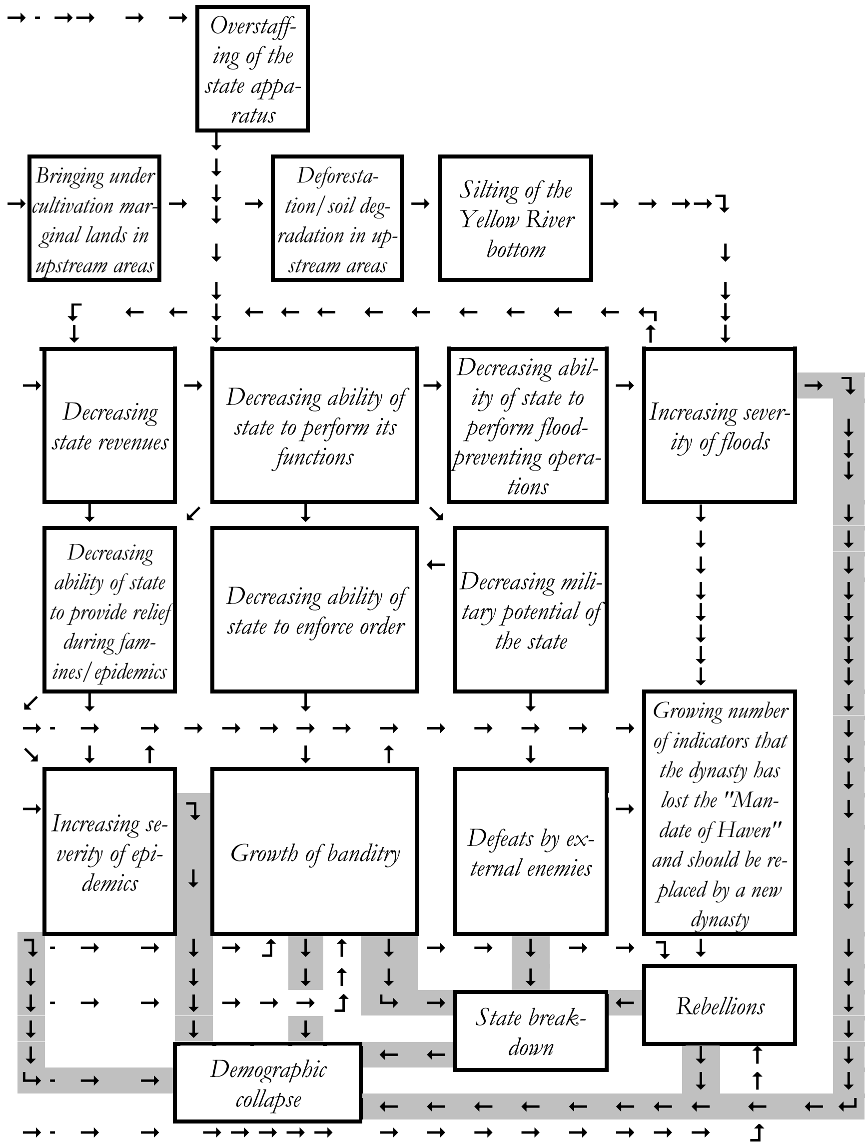


Diagram 2.26/2. Functional Scheme of a Pre-Industrial Chinese Demographic Cycle (pre-collapse and collapse phases) (Part 2)



Due to the shortage of space it turned out to be impossible to mark in the scheme above all the relationships.

For example, defeats by external enemies and growth of banditry lead to further declines in state revenues; increasing severity of famines leads to growth of banditry, which in its turn contributes to the rise of rebellions.

Only some peasants who loose their lands become tenants.[22] As was shown by Nefedov (2002a; 2004), it does not make sense for a landlord to rent out his land in plots barely sufficient to provide subsistence for a tenant and his family. As the standard rent rate in China was 50%, such plots would be at least twice as large. Hence, if two poor peasants having minimum size plots each have to sell their land, only one of them will be able to accommodate himself in his village as a tenant. The other will have to accommodate himself in some other ways. One of the possibilities was to find an alternative employment in non-agricultural sector, *e.g.*, in cities. As was suggested by Nefedov, the very process described above would in fact tend to create new possibilities for such employment, as landowners were more likely than poor farmers to buy goods produced in cities. This is confirmed by historical data indicating that the fastest growth of cities (and, hence, overall sociocultural complexity) tends to occur during the last phases of demographic cycles. However, not all the product paid by tenants to the landlords would find its way to those landless who tried to accommodate themselves in the non-agricultural sector of economy; hence, some of them would tend to accommodate themselves through illegal means, thus, leading to the growth of banditry. Other important relations not indicated in the scheme are the negative feedbacks between famines, infanticide *etc.* and population growth.

With respect to the relationship *Elite Overpopulation – Overstaffing of the state apparatus – Decreasing ability of state to provide relief during famines* the following illustration seems to be relevant:

"By Chia-ch'ing times (1796 –1820 – A.K, A.M., D.K.) this vast grain administration had been corrupted by the accumulation of superfluous personnel at all levels, and by the customary fees payable every time grain changed hands or passed an inspection point… The grain transport stations served as one of the focal points for patronage in official circles. Hundreds of expectant officials clustered at these posts, salaried as deputies (*ch'ai-wei* or *ts'ao-wei*) of the central government. As the numbers of personnel in the grain tribute administration grew and as costs rose through the eighteenth century, the fees payable for each grain junk increased accordingly. Where in 1732 fees had ranged from 130 to 200 taels per boat, by 1800 they had grown to 300 taels, in 1810 to

[22] As was shown by Shepherd (1988), this was just one of the sources of the origins of tenancy. Another was created by the capital investments of landowners in various land-improvement schemes (irrigation, land reclamation *etc.*). What is more, Shepherd suggests that in Late Imperial and especially Republican China the second source was even more important than the first. However, his own data also indicate that during earlier cycles the first source of tenancy was more important than in the latest periods of Chinese history.

500, and by the early Tao-kuang period (1821), to 700 or 800 taels" (Mann Jones and Kuhn 1978: 121).

Note that we are dealing here with a system that had been extremely effective during earlier phases of the cycle:

"In the autumn and winter of 1743 – 1744, a major drought afflicted an extensive portion of the North China core, resulting in a virtually complete crop failure. The famine-relief effort mounted by the court and carried out by ranked bureaucrats was… stunningly effective. Ever-normal and community granaries were generally found to be well stocked, and the huge resources of grain in Tongzhou and other depots were transported in time to key points throughout the stricken area. Networks of centers were quickly set up to distribute grain and cash, and soup kitchens were organized in every city to which refugees fled. In the following spring, seed grain and even oxen were distributed to afflicted farming households. As a result of this remarkable organizational and logistic feat, starvation was largely averted, and what might have been a major economic dislocation had negligible effect on the region's economic growth" (Skinner 1985: 283).

Floods: "Crises in the grain transport system were part of a general breakdown of public functions in the early decades of the [19th] century, stemming in part from bureaucratic malfeasance. In the case of grain transport, malfeasance merely compounded physical difficulties in a complex canal system that was joined at its mid-point to the Yellow River Conservancy (responsible for flood-prevention activities – A.K., A.M., D.K.). The physical difficulties of the system stemmed from silting caused by heavy soil erosion… By the late eighteenth century, the bed of the Yellow River had risen to dangerous heights, threatening the dikes and causing observers to predict the change in its course which finally came in 1853… Carelessness, ill-advised economies and intentional negligence in the Yellow River Conservancy had become a marked concern in official memorials after 1780, and corruption continued to plague the administration in the early nineteenth century. By many accounts, the aim of the water conservancy administration appears not to have been flood prevention, but rather the keeping of a careful balance whereby floods could occur at intervals regular enough to justify a continuing flow of funds into the water conservancy administration. Stories of three-day banqueting circuits and continuous theatrical performances along the south river conservancy suggested that only 10 per cent of the sixty million taels that annually supported the water conservancy were spent legitimately… By the Tuo-kuang era (1821 – 1850 – A.K., A.M., D.K.) the water conservancy, like the Grand Canal, had become a haven for unemployed bureaucrats" (Mann Jones and Kuhn 1978: 121).

It appears important to note that the functional scheme above does not account for negative feedbacks (*e.g.*, the negative feedback between the growth of female infanticide rates [ultimately caused by population pressure] and the population growth rates). Note that not all such negative feedbacks have been adequately spelled out even yet – *e.g.*, the influence of the growth of monasticism (caused to a considerable extent ultimately by population pressure) on population growth rates.

Some of the mechanisms outlined in the scheme above are rather China-specific, for example, *Bringing under cultivation marginal lands in upstream areas* → *Deforestation/soil degradation in upstream areas* → *Silting of the Yellow River bottom* → *Increas-*

ing severity of floods → *Growing number of indicators that the dynasty has lost the "Mandate of Haven" and should be replaced by a new dynasty* → *Rebellions*. One could hardly find this mechanism working in, say, Egyptian political demographic cycles (see the next issue of our *Introduction to Social Macrodynamics* [Korotayev and Khaltourina 2006: Chapters 2–5]).

Some other factors have countervailing effects. For example, female infanticide, on the one hand, delays demographic collapse by decreasing population growth rate; but, on the other hand, it speeds it up by promoting the growth of banditry, as well as numbers of males having no chance to get married, who make ideal potential recruits both for bandit networks and for rebel armies. Though such factors are immensely important if we would like to model dynamics of many particular variables during demographic cycles (for example, life expectancies at age 1 and higher [as was convincingly demonstrated by Lavely and Wong 1998: 736–8])[23], it seems possible to ignore them on the level of basic models of demographic cycles. Hence, in the next chapter we will restrict ourselves to the modeling of just a few of what we consider the most basic mechanisms of political-demographic cycle dynamics.

[23] And we believe such factors should be taken into account in future more comprehensive models.

Chapter 3

A New Model of Pre-Industrial Political-Demographic Cycles

by Natalia Komarova and Andrey Korotayev

The focus of the present chapter is not to fit the existing historical data, with all of its intricate features. Therefore, we do not feed into the model external warfare or temperature variables. Instead, we would like to mimic the qualitative behavior of the system in order to see whether the historical dynamics are consistent with the verbal explanations offered by various authors. We would like to understand the way annual climatic variations interact with population density to produce a demographic collapse through an increased frequency of internal warfare. We would also like to see how a country emerges from such a "state of disarray", and what factors influence this "intercycle" period. Internal warfare and its inertia will play an important part in this model.

The only exogenous variable in our model is fluctuating climate (as reflected by a fluctuating harvest yield). We will run our model and observe how cycles are formed, and what influences their period and amplitude. We set up the model as a system of difference equations where the value of the variable in a certain year is defined by the state of the system for the previous year.

We denote by N_i the number of peasants in year i. Let us suppose that the total area of the land available for agriculture, is A_{total}, and the area per peasant is $Area_i$. In times of peace, the amount of land per peasant is $Area_i = A_{total}/N_i$, that is, all available arable land is being used.

Let us denote by H_0 the average amount of food harvested by a peasant each year, measured per unit area. Every year, due to changing weather factors, the harvest yields will be different. We model this by letting the harvest variable be

$$Harvest_i = H_0 \times random\ number_i^{1}. \qquad (3.1)$$

The amount of food per person in year i is then given by $Food_i = Harvest_i \times Area_i$.

There is a minimum amount of food needed for a peasant to survive each year; we call it $Food_{min}$. Then the quantity $dF = Food - Food_{min}$ is the per capi-

[1] In the simulation whose results are presented at the end of this chapter its range is set at 0.85 to 1.15.

ta food surplus. In a good year, this quantity is positive, in a bad year it is negative (food shortage). The population grows, or shrinks, depending on this factor. Namely, the amount of population growth per year is directly proportional to dF, and if $dF > 0$, then the population will grow; if $dF < 0$, it will shrink. This is captured by the following basic population dynamics model:

$$N_{i+1}=N_i\,(1 + \alpha \times dF),$$

where α is a coefficient; we restrict the growth rate, $\alpha \times dF$ to a maximum of 3% a year. This model implicitly includes the carrying capacity in the following way: if there is much available land, then the peasants will have large allotments and will collect enough food to feed themselves, even in difficult years. As a result, the food surplus will be positive, and the population will grow. New peasants will need land, and therefore the area per peasant will decrease (the total area of land available for agriculture is assumed to be fixed). As a result, the food surplus will be lower, and the growth will slow down, until the system reaches a "dynamic equilibrium". This is a typical Malthusian growth model, leading to a logistic growth curve with saturation.

In reality, things are more complicated, and the first factor that we take into account is the presence of the state. We assume that the state collects taxes; with the amount of taxes per household (in years of peace) determined on the basis of food surplus. We assume the following taxation scheme: If there is additional food, the state collects a fixed fraction of food surplus. If there is shortage of food, the state does not collect taxes. A state-owned food reserve is formed, which is then used to feed the starving people in the years of poor yield. We keep track of the state-owned food reserve by means of the variable S_i. If the food surplus is positive, there will be an increase in the food reserve by the amount of $N_i \times tax \times dF$, where *tax* is the proportion of the food surplus that is moved to the counter-famine reserve[2]. If there is a shortage of food, then the necessary amount of stored food is distributed among the peasants, and the overall amount of stored food decreases; indeed, it can be completely depleted in bad years. If we include food storage in the model, we see that in the beginning, as the population grows, the food storage increases, and when the popula-

[2] The presence of a state-sponsored relief system may seem to be too China-specific. Admittedly, developed systems of this kind are very rarely found within complex agrarian systems outside East Asia. However, famine-relief counter-crisis subsystems of some kind are found within an overwhelming majority of complex preindustrial states. The most wide-spread type was based on the private stores of food resources held by elites (landowners *etc.*). During famines the elites would tend to use those storages to provide a sort of relief to at least some categories of commoner population. Landowners, after all, normally would have an interest in their tenants not dying out, and naturally would provide some support to them in such cases. No doubt such relief was rarely altogether altruistic: landowners could provide food to peasants in order to indenture them and to get their land. But regardless of its motive, such aid would have helped substantial parts of affected populations to survive through lean years. For the sake of simplicity, in our model both main types of pre-industrial counter-crisis relief subsystems are merged in one (hence, taxes are merged with rents).

tion reaches saturation at the carrying capacity level, the food storage gets depleted after a few bad years, and continues to oscillate at low levels.

Next, we need to add some political factors to this purely economic model. In times of trouble, some peasants may be tempted to leave/sell their land and obtain food by joining bandits or rebels[3]. The less food is available, the more likely peasants will be to make this decision. Thus we introduce the variable R_i, the number of bandits in year i. The number of peasants turning bandits each year is set at $dR_i = -N_i \times dF/Food_{min} \times \alpha_{out}$ in the years when there is food shortage, and 0 in prosperous years. Here, the constant α_{out} is "peasant-bandit transformation rate", basically describing the likelihood that each person will make the decision to become a bandit, depending on how large the food shortage is.

In order to describe the population dynamics of the bandits, let us suppose that the bandits survive by robbing the peasants. The more peasants are available, the easier it is for a bandit to survive. Let us introduce the quantity $\delta_{i,}$, equal to $\delta_i = 1 - N_i / (10 R_i)$ if $N_i < 10 R_i$, and $\delta_i = 0$ otherwise. Then the equation for the number of bandits each year can be written as

$$R_{i+1}=R_i (1 - \beta - \delta_{i,}) + dR_i .$$

This equation states that the population of bandits decreases in the absence of new recruits. We assume that bandits rarely have families, and that they have an increased death rate as a result of the hardships of their life style. The death rate of bandits consists of two parts, β – the constant background rate, and δ_i which depends on how successful the bandits are at extracting food from the peasants. If the peasant ÷ bandit ratio is greater than 10, we assume that the bandits can easily feed themselves; the smaller the ratio, the harder it is for the bandits to survive.

For the next step, we need to discuss the impact of banditry on the lives of peasants and on the general condition of the state. First of all, the presence of bandits ravaging the countryside introduces a certain "fear factor". If the population of the country decreases due to the intensification of internal warfare, much land becomes free, and in principle could be cultivated by the remaining peasants. However, this is not likely to happen, since peasants tend to stay in protected areas, and agricultural activities outside the limited protected region are considered unsafe. This can be modeled by assuming that in the presence of bandits, some parts of unoccupied land are not available for peasants: $Area_{i+1} = A_{total}/(N_i + 10R_i)$. This means that in times of peace ($10R_i << N_i$), all available area is distributed among the peasants. In times of war ($10R_i \sim N_i$), the peasants

[3] We follow Chu and Lee (1994) in denoting as "bandits" both bandits and rebels (note that Chu and Lee in their turn follow the Chinese tradition in denoting both categories with one term [*fĕizéi*]). The logic behind this merging is that both groups produce rather similar effects on population dynamics: rebels, even when fighting with the aim of improving the life of peasants, in order to feed themselves would still have to take food from peasants.

tend to stick to their land in safe areas, expansion to available uncultivated lands in unsafe areas does not happen, and effective carrying capacity of land decreases. Thus banditry/rebellions/internal warfare are the basic reasons for demographic collapse as described in our model.

Secondly, warfare has a negative impact on the ability of the state to collect taxes. In order to capture this, we introduce the "tax collection effectiveness coefficient", U. Depending on the level of internal warfare (measured best by the number of bandits), this coefficient is equal to 0 in times of war, and it is equal to 1 in times of peace. We assume that during war, the state is weakened and its ability to collect taxes is impaired. This is captured by the following equation:

$$S_{i+1} = S_i + dS \times U ,$$

where dS is the tax collected or the food from the storage given back to the peasants, exactly as described above, and U quantifies the efficiency of the state and the impact of war on tax collection. In time of war, U is close, or equal, to zero, and taxes are not collected efficiently because the state infrastructure is partially destroyed.

To summarize, we have included three main elements in this model. (1) The Malthusian-type economic model, with elements of the state as tax collector (and counter-famine reserve sponsor), and fluctuating annual harvest yields; this describes the logistic shape of population growth. It explains well the upward curve in the demographic cycle and saturation when the carrying capacity of land is reached. (2) Banditry and the rise of internal warfare in time of need are the main mechanism of demographic collapse. Personal decisions of peasants to leave their land and become warriors/bandits/rebels are influenced by economic factors. (3) The inertia of warfare (which manifests itself in the fear factor and the destruction of infrastructures) is responsible for a slow initial growth and the phenomenon of the "intercycle".

Let us put all the definitions and equations together in a coherent set, describing demographic cycles of complex agrarian systems:

- N_i is the number of peasants;
- R_i is the number of bandits;
- S_i is the amount of food storage;

$Harvest = H_0 + random\ fluctuations$; (3.1)

- U is the "tax collection effectiveness coefficient":

$$U = \begin{cases} (1 - R_i/0.03N_i)^3 & \text{if } R_i < 0.03N_i, \\ 0 & \text{otherwise;} \end{cases}$$

$Area_{i+1} = A_{total} / (N_i + 10R_i)$;

$Food_i = Harvest_i \times Area_i$;

- dF is per capita "food surplus" (which could be not only positive, but also negative):

$dF_i = Food_i/N_i - Food_{min}$;

$dS_i =$	$N_i \times tax \times dF_i$	if there is additional product,
	$N_i \times dF_i$	if there is shortage of food ($dF < 0$) and enough storage ($\|N_i \times dF\| < S_i$),
	$-S_i$	if there is considerable shortage of food ($dF < 0$; $\|N_i \times dF\| < S_i$);

- dF'_i is "effective" food surplus, after tax/rent payment, or after receiving state help;

$dF' = dF_i - dS_i/N_i$;

- α is related to the growth rate of peasants. We assume that the quantity $\alpha \times dF'$ cannot exceed 0.03.
- dR_i is number of peasants turned into bandits in year i:

$dR_i =$	$-N_i \times \alpha_{out} \times dF/Food_{min}$	if there is not enough food,
	0	if there is enough food;

- α_{out} is "peasant-bandit transformation rate";
- $\beta + \delta_I$ is death rate of bandits; β is the constant background rate;

$\delta_i =$	$1 - N_i/10R_i$	if $N_i < 10R_i$,
	0	otherwise;

- *rob* – bandit-related death rate of peasants.

The difference equations (equipped with appropriate initial conditions), are:

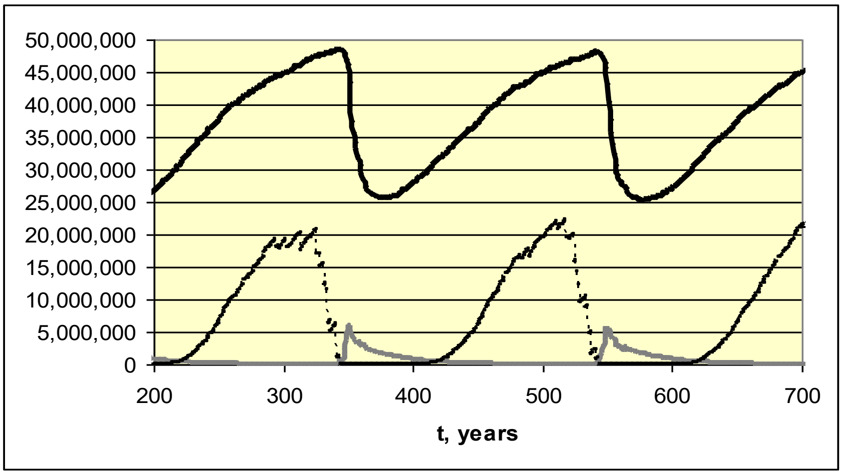
$$S_{i+1} = S_i + dS \times U \,, \qquad (3.2)$$

$$N_{i+1} = N_i \times (1 + \alpha \times dF') - dR_i - rob \times N_i \times R_i \,, \qquad (3.3)$$

$$R_{i+1} = R_i \times (1 - \beta - \delta_i) + dR_i \,. \qquad (3.4)$$

This model generates the following dynamics (see Diagram 3.1):

Diagram 3.1. Dynamics Shape Generated by the Model



NOTE: *thick solid black curve* – total population ("peasants" + "bandits"), persons; *thick solid grey curve* – number of "bandits"; *thin broken black curve* – food reserve, minimum annual food rations (each of which secures a survival of one person through one year). The diagram reproduces the results of a simulation with the following values of parameters and initial conditions: N_0 = 30,000,000 peasants; A_{total} = 50,000,000 units, it is assumed that one unit produces under average climatic conditions one minimum annual food ration (MAFR), *i.e.*, an amount of food that is barely sufficient to support one person for one year, that is, H_0 = 1 MAFR per unit per year; *random number* range is between 0.85 and 1.15, thus $Harvest_i$ (per unit yield in year *i*) randomly assumes values in the range 0.85 to 1.15 MAFR per unit per year; $Food_{min}$ = 1 MAFR; R_0 = 1000 bandits; S_0 = 0 MAFR; α = 0.04 MAFR^{-1}; *tax* = 0.05; α_{out} = 0.1; β = 0.03; *rob* = 0.000000002.

A numerical investigation of the effect of parameter values on the dynamics of our model indicates that the main parameters that affect the period of the cycle are the proportion of resources annually accumulated in counter-famine reserves (*tax*), peasant-bandit transformation rate (α_{out}), and the magnitude of climatic fluctuations (M_c).[4] Longer cycles of more than three centuries in period obtain for higher values of *tax* and lower values of α_{out} and M_c, whereas the cycles' length becomes shorter with lower *tax*, and higher α_{out} and M_c. This suggests that the length of the cycles would increase with the growth of the strength of counter-famine and law-enforcement subsystems, which seems to correspond quite well to the actually observed historical dynamics (see, *e.g.*, Nefedov 2000a, or the next issue of our *Introduction to Social Macrodynamics* [Korotayev and Khaltourina 2006]).

We believe that the proposed model combines positive aspects of earlier models that have not previously been combined within one model. Unlike Nefedov's model, but like some predator-prey logic based models it accounts for significant intercycle periods. On the other hand, unlike the latter, due to the inclusion of the famine relief subsystem dynamics our model can now account for lengthy periods of very slow and unsteady population growth (when much of the population had inadequate per capita acreage and there existed very strong incentives to innovate in order to raise the carrying capacity of land).[5] However, like most of the earlier models, it is based on the assumption that subsistence technology development level is a constant. As a result it only describes "secular cycles", but not "millennial trends". Is it possible to develop mathematical models that describe both secular cycles and millennial trend dynamics? We shall try to answer this question in the next chapter.

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[4] On the other hand, the "bandit death rate" (β) affects strongly the length of the intercycles (the smaller the bandit death rate, the longer the intercycles), whereas bandit-related death rate of peasants (*rob*) affects strongly the amplitude of cycles (the higher the bandit-related death rate of peasants, the higher the cycle amplitude). Note that β can be regarded as a measure of a political system effectiveness in suppression of banditry, whereas the serious impact of *rob* seems to reflect the importance of a systems's cultural characteristics influencing the ease with which a life of another person could be taken.

[5] In the next chapter we will see why this is so important (see also the next issue of our *Introduction to Social Macrodynamics* [Korotayev and Khaltourina 2006]).

<u>Chapter 4</u>

Secular Cycles and Millennial Trends[1]

Initially, we want to consider what effects could be produced by the long-term interaction of millennial macrotrends of the World System development and shorter-term cyclical dynamics. Among other things this will make it possible for us to demonstrate how even rather simple mathematical models of pre-industrial political-demographic cycles could help us to account for a paradox that has been encountered recently by political anthropologists.

At least since 1798 when Thomas Malthus published his *Essay on the Principle of Population* (1798) it has been commonly assumed that in pre-industrial societies the growth of population density tends to lead to increase in warfare frequency.[2] For example, in Anthropology this assumption forms one of the foundations of the "warfare theory" of state formation. Indeed, according to this theory population growth leads to an increase in warfare which can lead, under certain circumstances, to political centralization (Sanders and Price 1968: 230–2; Harner 1970: 68; Carneiro 1970, 1972, 1978, 1981, 1987, 1988, 2000a: 182–6; Harris 1972, 1978; 1997: 286–90; 2001: 92; Larson 1972; Webster 1975; Ferguson 1984; 1990: 31–3; Johnson and Earle 1987: 16–8).

However, some anthropologists have raised doubts regarding this relationship (Vayda 1974: 183; Cowgill 1979: 59–60; Redmond 1994; Kang 2000). On the other hand, Wright and Johnson (1975) have shown that in South-West Iran population density in the state formation period did not grow, but rather declined, while Kang's analysis of data for the state formation period Korea reveals only a very weak correlation between warfare frequency and population density (Kang 2000). Finally, cross-cultural testing performed by Keeley (1996: 117–21, 202) did not confirm the existence of any significant positive correlation between the two variables, which seems to have convinced Johnson and Earle to drop, from the second edition of their book, the mention of population pressure as a major cause of warfare in pre-industrial cultures (Johnson and Earle 2000: 15–6).

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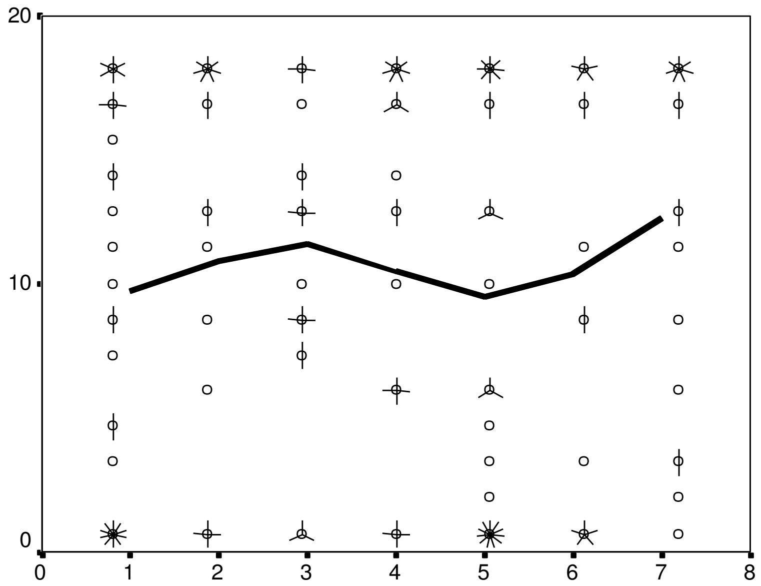
[1] The first half of this chapter has been prepared on the basis of an article written by the first author of this monograph in collaboration with Peter Turchin (Turchin and Korotayev 2006).

[2] Indeed, Malthus (1798/1978) saw war as one of the standard consequences of overpopulation along with disease and famine.

We tested this hypothesis ourselves using the Standard Cross-Cultural Sample database (STDS 2002). The first test seems to have confirmed the total absence of any significant correlation between population density and warfare frequency (see Diagram 4.1):

Diagram 4.1. Population Density × Warfare Frequency. Scatterplot with fitted Lowess line. For the Standard Cross-Cultural Sample (Murdock and White 1969)



NOTE: ***Rho* = 0.04, *p* = 0.59 (2-tailed)[3].** POPULATION DENSITY CODES: 1 = < 1 person per 5 sq. mile; 2 = 1 person per 1–5 sq. mile; 3 = 1–5 persons per sq. mile; 4 = 1–25 persons per sq. mile; 5 = 26–100 persons per sq. mile; 6 = 101–500 persons per sq. mile; 7 = over 500 persons per sq. mile. WARFARE FREQUENCY CODES: 1 = absent or rare; 2–4 = values intermediate between "1" and "5"; 5 = occurs once every 3 to 10 years; 6–8 = values intermediate between "5" and "9"; 9 = occurs once every 2 years; 10–12 = values intermediate between "9" and "13"; 13 = occurs every year, but usually only during a particular season; 14–16 = values intermediate between "13" and "17; 17 = occurs almost constantly and at any time of the year. DATA SOURCES. For population density: Murdock and Wilson 1972, 1985; Murdock and Provost 1973, 1985; Pryor 1985, 1986, 1989; STDS 2002. Files stds03.sav (v64), stds06.sav (v156), stds54.sav (v1130). For war-

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[3] Use of Spearman's *Rho* (and associated measures of significance) reflects the fact that we were dealing with variables measured on an ordinal scale.

fare frequency: Ross 1983, 1986; Ember and Ember 1992a, 1992b, 1994, 1995; Lang 1998; STDS 2002. Files stds30.sav (v773, v774), stds78.sav (v1648–50), stds81.sav (v1748–50).

The absence of a significant correlation between the two variables seems to be entirely evident. However, let us ask ourselves the following question: Does the proposition that growing population density tends to lead to a rise in warfare's frequency necessarily imply the presence of a positive correlation between the two variables under consideration? Some scholars certainly seem to think exactly this way. Note, *e.g.*, that Keeley (1996: 117–21, 202) thinks that he has refuted the hypothesis under consideration precisely by demonstrating the absence of such a correlation. However, we believe that to operationalize the hypothesis under consideration this way is naïve.

The point is that, as we shall see below, the growth of population density in preindustrial cultures does lead to a rise in warfare's frequency. But how would the rise of warfare frequency affect population density? Certainly, it would lead to the decline of population density. This is not only because frequent warfare would decrease the number of people in any given zone. The other important point is that frequent warfare also would reduce the *carrying capacity* of the given zone. Within such zones affected by constant warfare, people would tend to inhabit places that can be made defensible (see, e.g., Wickham 1981; Earle 1997: 105–42; Turchin 2003b: 120). Fearful of attack, people cultivate (or exploit in other ways) only a fraction of the productive area, specifically, the fraction in proximity to fortified settlements.

In fact, it is quite clear that we have a dynamic relationship here which can be described by non-linear dynamic models: the rise of population density leads to the rise of warfare frequency, but the growth of warfare frequency leads in its turn to a *decline* of population density. What kind of linear correlation would such a relationship produce?

The simplest model describing this type of relationship is the "predator – prey" one (Lotka 1925; Volterra 1926). There are good grounds to expect this model to be relevant in our case, because the relationship between population density and warfare frequency appears to have the same basic logic as the one between prey and predator populations.

This simple model looks as follows:

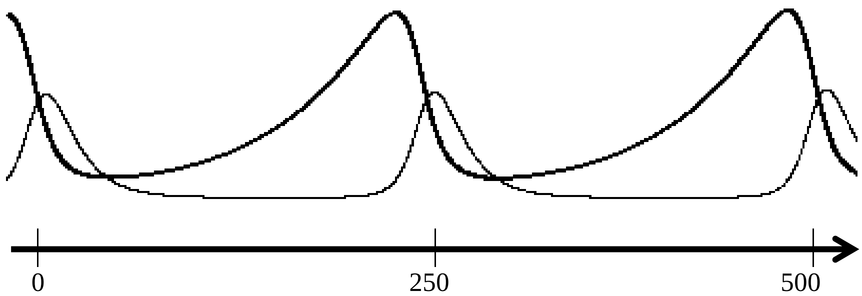
$$\frac{dx}{dt} = Ax - Bxy \qquad (4.1)$$
$$\frac{dy}{dt} = Cxy - Dy\,,$$

where x is population density ["prey"], y is warfare frequency ["predator"], and A, B, C, D are coefficients.

Note that though this model implies a perfect 1.0 level nonlinear correlation between the variables, it predicts that tests of linear relationship for the same data will detect a weak negative correlation between warfare frequency and population density (especially if the linear ranked correlation is measured).

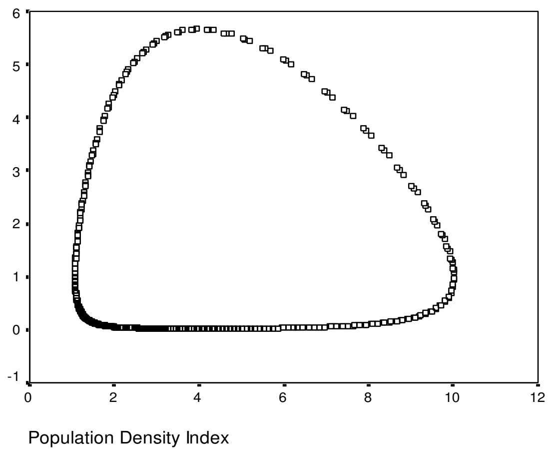
For example, with *A* = 0.02 (which is, by the way, the normal unlimited annual demographic growth rate for preindustrial cultures [Turchin 2003b]), *B* = 0.02, *C* = 0.025, and *D* = 0.1, the temporal dynamics appear as follows (see Diagram 4.2):

Diagram 4.2. Temporal Dynamics of Population Density *X* (thick curve) and Warfare Frequency *Y* (thin curve) with *A* = 0.02, *B* = 0.02, *C* = 0.025, and *D* = 0.1



The scatterplot of relationship between the two variables under consideration in this case will look as follows (see Diagram 4.3):

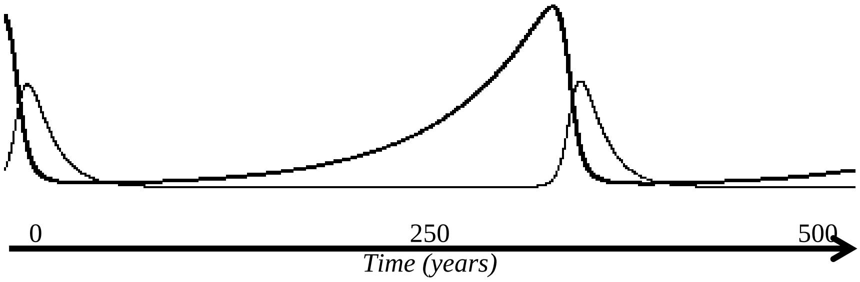
Diagram 4.3. Scatterplot of Relationship between Population Density and Warfare Frequency predicted by the model with *A* = 0.02, *B* = 0.02, *C* = 0.025, and *D* = 0.1



Quite predictably with such a shape of distribution the test of linear relationship for 500 cases detects beyond any doubt a weak but highly significant negative ranked correlation (*Rho* = – 0.19, *p* = 0.00001, 2 tailed).

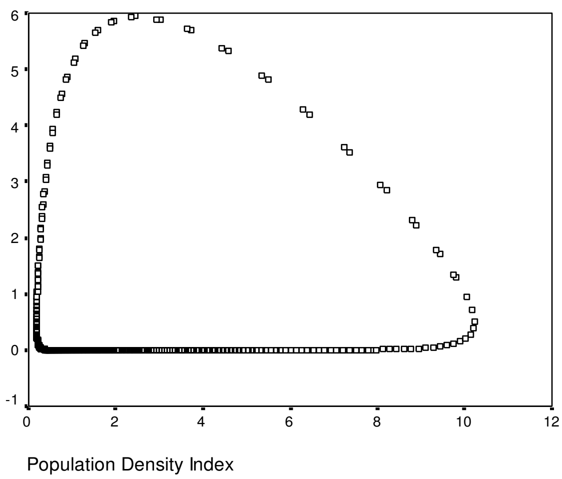
With *A* = 0.02, *B* = 0.04, *C* = 0.04, and *D* = 0.1, the temporal plot of the variables under consideration looks as follows (see Diagram 4.4):

Diagram 4.4. Temporal Dynamics of Population Density *X* (thick curve) and warfare frequency Y (thin curve) with A = 0.02, B = 0.04, C = 0.04, and D = 0.1



The scatterplot of relationship between the two variables under consideration in this case will look as follows (see Diagram 4.5):

Diagram 4.5. Scatterplot of Relationship between Population Density and Warfare Frequency predicted by the model with *A* = 0.02, *B* = 0.04, *C* = 0.04, and *D* = 0.1



With this shape of distribution the test of linear relationship for 500 cases detects a much stronger and even more highly significant negative ranked correlation between the variables under consideration (*Rho* = – 0.45, p = 0.000002, 2 tailed).[4]

This negative correlation is easy to explain. What is more, the model seems to correspond quite well to known facts. After all, population growth will be to some extent inhibited by frequent warfare; hence, periods of significant population growth should almost by definition coincide with periods of relatively low warfare frequency. On the other hand, as was mentioned above, the growth of warfare frequency above a certain level will lead to immediate and rapid decline of population density, whereas the drop of warfare frequency would lead to immediate increase in the population density.[5]

The other important point is that warfare has a certain amount of inertia, and so does not decline immediately after the drop of population. For most preindustrial cultures this inertia has a very straightforward explanation. As has been shown by Keeley (1996), the most frequent cause of warfare is simply revenge. Now, suppose that as a result of a sharp decline of population density caused by extensive warfare the population-pressure-induced reasons for war have disappeared; yet, the very high level of warfare in the previous period of time would almost by definition imply a high level of warfare in the given period, since the earlier period would have left a large number of killings and other hostile acts still to be avenged.[6]

Thus we appear to have two time lags which would tend to produce negative correlations. As a result, we would have relatively many cases of high population density accompanied by low warfare frequency, as well as low population density accompanied by high warfare frequency, whereas the number of cases with high population density accompanied by high warfare frequency would be zero, or very close to zero; hence, such lag effects would result in negative linear correlations.

Due to reasons which we will discuss at the end of this chapter, this negative correlation is observed especially among cultures with relatively similar technological bases resulting in fairly similar values of the carrying capacity of land. In the Standard Cross-Cultural Sample this correlation can be detected for a subsample of chiefdoms (*i.e.*, cultures with 1 or 2 levels of political integration

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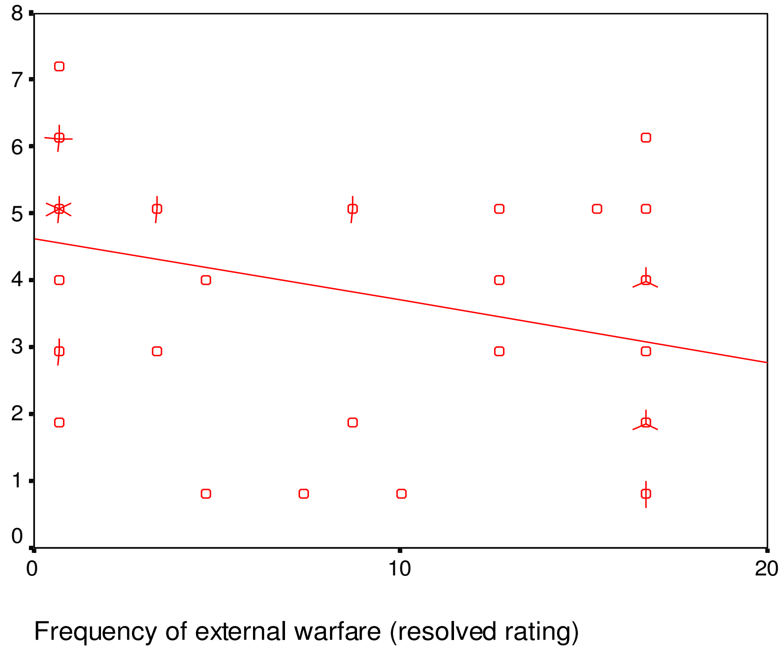
[4] Negative correlations for this kind of model are much more likely to be detected if one measures Spearman's *Rho*, rather than Pearson's r. It might be argued, then, that we have "stacked the deck" by using the former rather than the latter. Note, however, that both the population density and the warfare frequency variables available in cross-cultural databases are ordinal-level, so that rank correlation (Spearman's *Rho*) turns out to be simply more appropriate methodologically.

[5] This is almost inevitable as the drop of the population density in the preceding prolonged period of frequent warfare would mean that the remaining population would have abundant resources immediately after the end of this period.

[6] Hence, those versions of the model above with the coefficient combinations implying such a time lag seem to correspond to historical reality rather closely.

above that of the individual community, having mostly fairly similar technological bases). This test detected the actual presence of a significant negative correlation between the population density and warfare frequency for chiefdoms (*Rho* = – 0.26, *p* = 0.02). Note that the correlation between population density and external warfare frequency for this subsample turned out to be stronger (*Rho* = – 0.40). Predictably it turned out to be particularly strong when the sample was further split into simple and complex chiefdoms (see Diagrams 4.6 and 4.7):

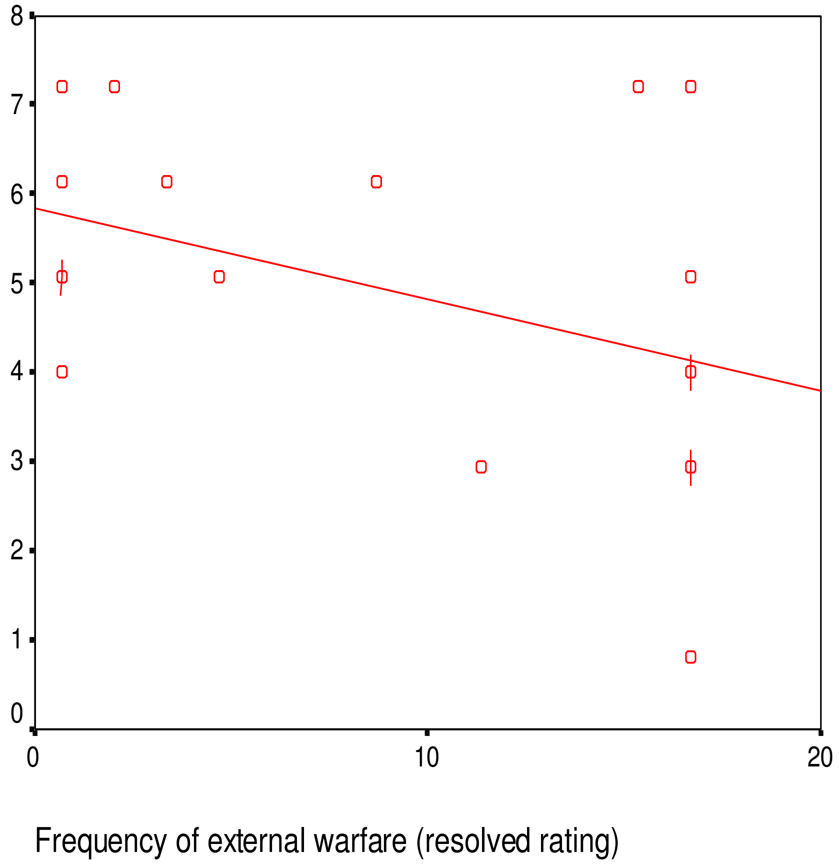
Diagram 4.6. Population Density × Warfare Frequency. Scatterplot with linear regression line. For the Standard Cross-Cultural Sample, subsample of simple chiefdoms[7].



NOTE: ***Rho* = – 0.44, *p* = 0.002 (1-tailed).**[8] For sources and codes see Diagram 4.1.

[7] Simple chiefdoms were selected using the variable JURISDICTIONAL HIERARCHY BEYOND LOCAL COMMUNITY (Murdock 1967, 1985; Murdock *et al.* 1999–2000; STDS 2002: file STDS10.SAV [v237]). The cultures with one level of political integration above the community were identified as having been organized politically as simple chiefdoms, or political forms of equivalent complexity (e.g., federations of communities).

Diagram 4.7. Population Density × Warfare Frequency. Scatterplot with linear regression line. For the Standard Cross-Cultural Sample, subsample of complex chiefdoms[9]



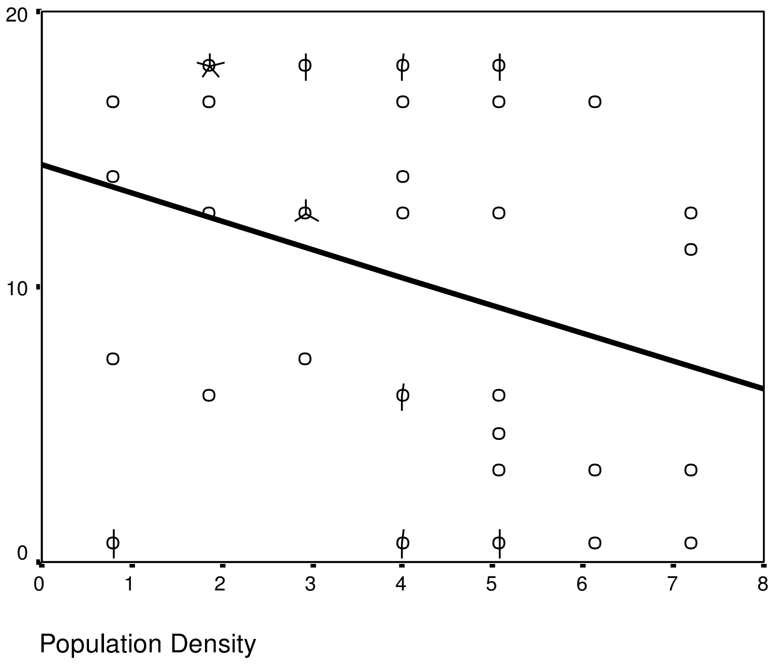
NOTE: ***Rho* = – 0.41, p = 0.04 (1-tailed).** For sources and codes see Diagram 4.1.

[8] As we had clear hypotheses predicting the correlation directions, and as all the correlations tested here and below turned out to be in the predicted direction, we used 1-tailed significance tests.

[9] Complex chiefdoms were selected using the variable JURISDICTIONAL HIERARCHY BEYOND LOCAL COMMUNITY (Murdock 1967, 1985; Murdock *et al.* 1999–2000; STDS 2002: file STDS10.SAV [v237]). The cultures with two levels of political integration above that of community were identified as having been organized politically as complex chiefdoms, or political forms of equivalent complexity (e.g., tribal confederations of the Iroquois type).

A similar correlation is also observed, for example, for cultures based on extensive agriculture (see Diagram 4.8):

Diagram 4.8. Population Density × Warfare Frequency. Scatterplot with linear regression line. For the Standard Cross-Cultural Sample, subsample of cultures based on extensive agriculture[10], scatterplot with a fitted regression line



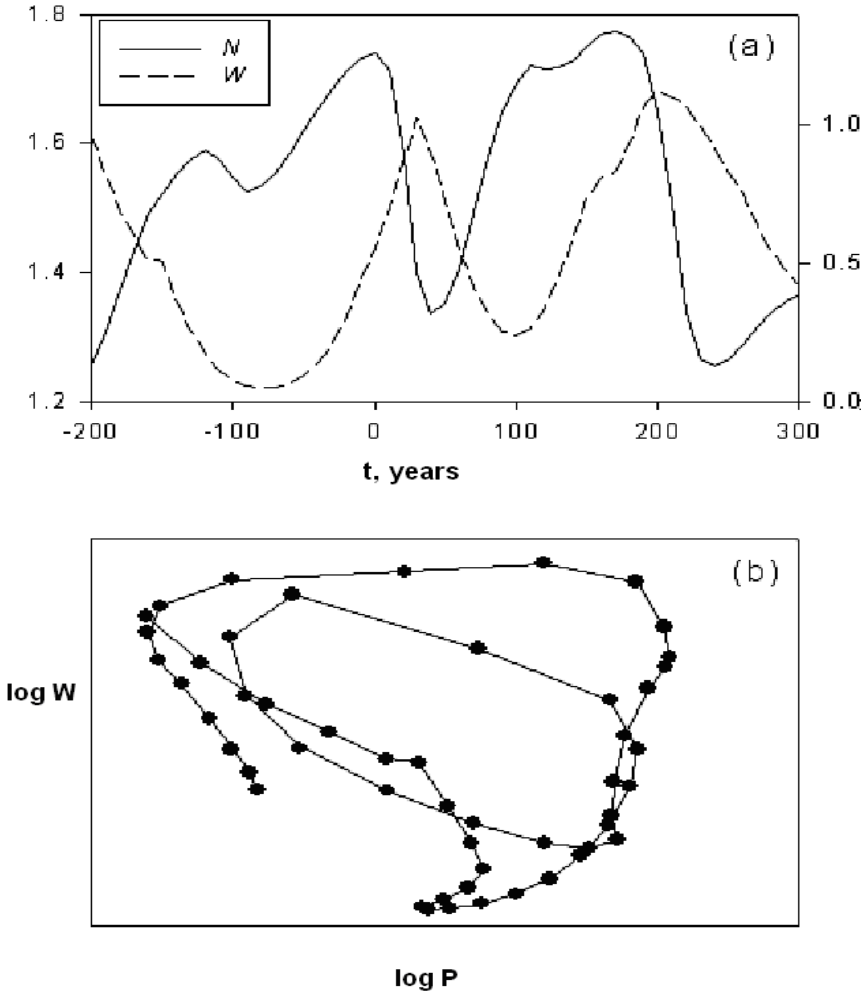
NOTES: ***Rho* = – 0.3, *p* = 0.025 (1-tailed).** For sources and codes see notes to Diagram 4.1.

The fact that population density and warfare frequency are characterized by an extremely close non-linear dynamic relationship, which on the surface appears as a relatively weak negative linear correlation, is especially clear when we have more or less exact long-term data for population density and warfare frequency

[10] Cultures based on extensive agriculture were selected using the variable INTENSITY OF CULTIVATION (Murdock 1967, 1985; Murdock *et al.* 1986, 1990, 1999–2000; STDS 2002: file STDS10.SAV [v232]). We selected cultures with value "3" of this variable ("Extensive or shifting cultivation, as where new fields are cleared annually, cultivated for a year or two, and then allowed to revert to forest or bush for a long fallow period" [Murdock 1967: 159, *etc.*]).

for concrete pre-industrial cultures (Turchin 2003b; Turchin and Korotayev 2006, see, e.g., Diagram 4.9):

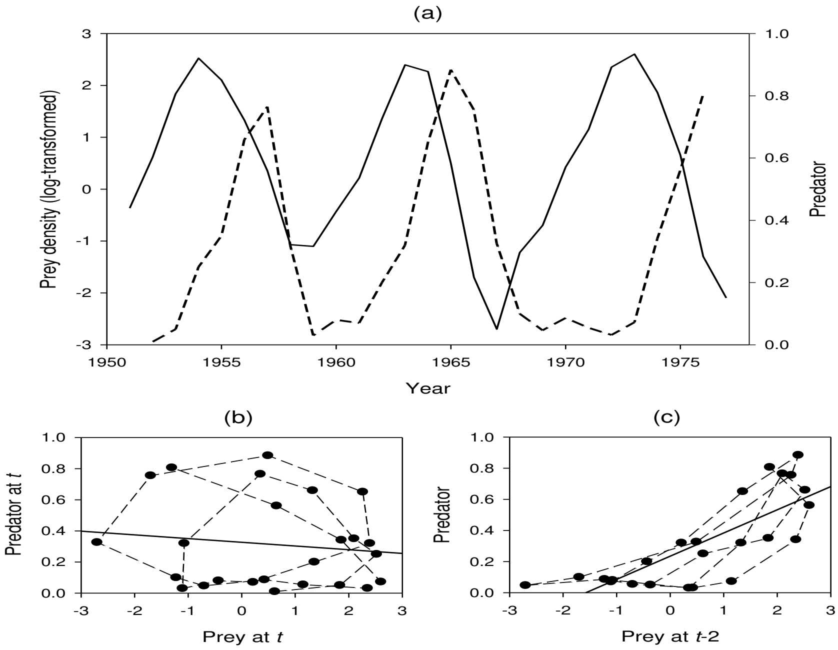
Diagram 4.9. Dynamics of Population (solid line) and Internal Warfare (broken line) in China from 200 BCE to 300 CE, temporal plot (Turchin and Korotayev 2006)



NOTES: (a) trajectories of population and internal warfare index; (b) variable dynamics in the phase space (X axis – logarithm of population; Y axis – logarithm of internal warfare index): $r = -0.37$, $p < 0.01$.

It might be revealing to compare these figures with the ones illustrating a classical prey-predator relationship. The data document population oscillations of prey, a caterpillar that eats the needles of larch trees in the Swiss Alps, and its predators, parasitic wasps. The caterpillar population goes through very regular population oscillations with the period of 8–9 years. Predators (here measured by the mortality rate that they inflict on the caterpillars) also go through oscillations of the same period, but shifted in phase by 2 years with respect to the prey (Diagram 4.10a). Almost 95% of variation in caterpillar numbers is explained by wasp predation (Turchin 2003a), but when we plot the two variables against each other we see only a weak, and negative correlation (Diagram 4.10b). If we plot predators against the lagged prey numbers, then we clearly see the positive correlation (Diagram 4.10c):

Diagram 4.10. Population dynamics of the caterpillar (larch budmoth) and its predators (parasitic wasps). (a) Population oscillations of the caterpillar (solid curve) and predators (broken curve). (b) A scatter plot of the predator against the prey. The solid line is the regression. Broken lines connect consecutive data points, revealing the presence of cycles. (c) A scatter plot of the predator against prey lagged by two years (Turchin 2003a)



However, why did our first cross-cultural test, which employed a sample that included societies with all possible degrees of cultural complexity stretching from the !Kung Bushmen to the Modern Chinese, fail to reveal *any* significant correlation between the variables under consideration?

To answer this question, let us try first to model how the military-demographic dynamics could change with the growth of political centralization. First of all, note that the growth of political centralization (that is, the transition from independent communities to simple, and then complex, chiefdoms and later to states and empires, which is accompanied by a hyperbolic growth of polity sizes) leads to the decrease of the relative "lethality" of warfare (see, e.g.: Nazaretyan 1995, 1999a, 1999b, 2001).

Indeed, on the one hand, for a small (< 50) independent local group the maximum value of the warfare frequency index ("17 = occurs almost constantly and at any time of the year") implies an almost inevitable and very serious depopulation. On the other hand, any accurate coder of cross-cultural data could hardly fail to assign to, say, Russia between 1820 and 1860 exactly the maximum value of this index (at least because of the Caucasus War that continued between 1817 and 1864, let alone numerous other wars, like the Crimean one). However, in this case this maximum value of the warfare frequency index was not accompanied by anything even remotely similar to the depopulation of Russia; what is more, throughout this exact period, Russia experienced a very rapid demographic growth (see, *e.g.*, Nefedov 2005). The explanation for this apparent paradox is, of course, very simple. The point is that within the developed states (even if still pre-Industrial), wars (especially external ones) were usually waged by relatively small professional well armed and trained armies. As a result, a country could be nominally in the state of war for many decades without experiencing any depopulation at all.

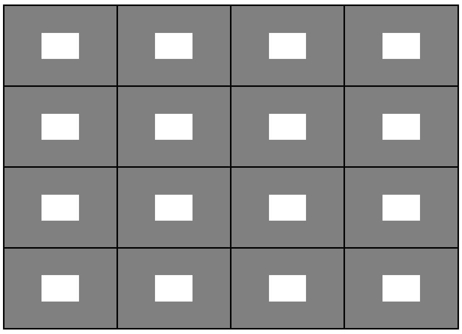
Note that such external wars would not normally lead to any significant decrease of the carrying capacity with respect to the territory in which the majority of the respective state's population lives.[11] In general, the larger the polity, the lower the negative influence of this polity's external wars on the carrying capacity of the territory controlled by this polity. Indeed, along the borders between those polities that wage constant wars against each other we usually observe considerable belts of economically unexploited (or underexploited) territories (see, e.g., Blanton *et al.* 1999).

It appears possible to demonstrate the effect of polity size growth in reducing external warfare's negative influence on carrying capacity with the help of the following model (see Diagram 4.11):

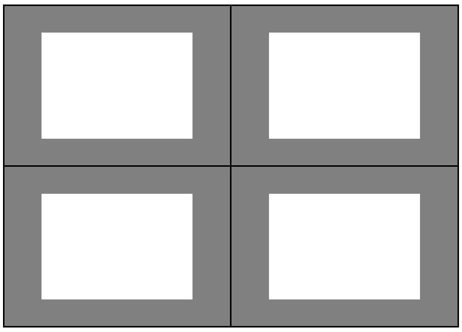
[11] This is valid more for external than for internal warfare. Thus, within supercomplex agrarian societies it is the internal warfare frequency that turns out to be connected with population density along the "predator – prey" model's lines. On the other hand, the external warfare frequency dynamics also turn out to be connected with the population density dynamics, but, as we shall see below, according to a totally different model.

Diagram 4.11. Influence of Frequent External Warfare on Carrying Capacity in a Zone Consisting of Simple Chiefdoms (a) and Complex Chiefdoms (b), a Model

(a) Simple Chiefdoms



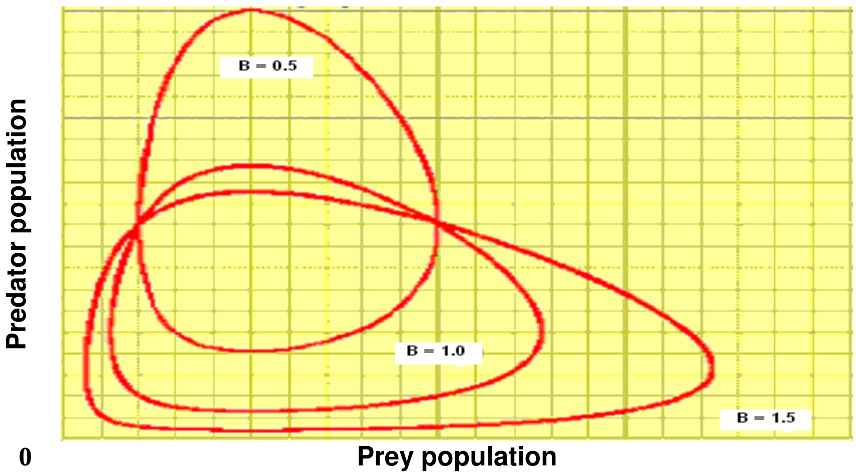
(b) Complex Chiefdoms



NOTE: Borders between polities are marked with solid lines. This model assumes that strips along the borders (marked with grey filling) are not exploited economically. As a result, frequent warfare decreases carrying capacity of a zone consisting of simple chiefdoms by almost 89%, whereas in an analogous zone consisting of complex chiefdoms it decreases the carrying capacity by less than 56%.

During the course of human history, the polity sizes have increased by 5 to 6 orders of magnitude (see, e.g.: Taagapera 1968, 1978a, 1978b, 1979, 1997; Carneiro 1978; Graber 1995 *etc.*); therefore the influence of this factor should have been very sizeable. The long-term trend towards the growth of political centralization tended to reduce the negative influence of frequent warfare on demographic dynamics in two ways: (1) through the professionalization of warfare and (2) through the growth of polity sizes, which entailed reduction of the negative influence of frequent warfare on carrying capacity. Is it possible to use the Lotka – Volterra equations to model how warfare's frequency would be affected by the long-term decrease of warfare's "lethality" that accompanied growing political centralization? This could be done very easily through the reduction of the value of coefficient *B*, which is none other than a coefficient of the lethal influence of the predator/warfare presence on the prey population/population density. If this is done, what will happen to the predator population dynamics? *Ceteris paribus* (that is with the same values of initial prey and predator populations, as well as with the same values of coefficients *A*, *C*, and *D*), the decrease of the value of coefficient *B* will lead to an upward drift of the system singular point (center)[12] in the phase space (see Diagram 4.12):

Diagram 4.12. Drift of the "Prey – Predator" System Center with Decrease of Lotka – Volterra Coefficient *B* Value from 1.5 to 0.5



NOTE: The values of coefficients *A*, *C*, and *D* were taken as 1.0 for all three simulations. The initial values of prey and predator populations were also identical for all three simulations.

The upward singular point (center) drift within such a phase space implies that the predator population increases for all the cycle phases; thus, the average predator population increases for any given year of the cycle.[13]

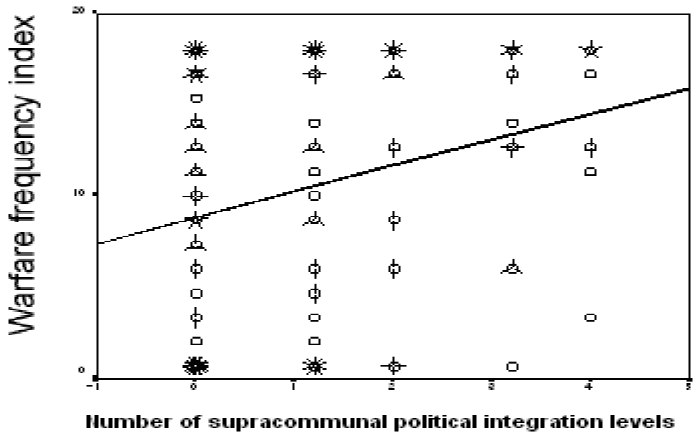
Hence, for traditional cultures[14] we have sufficient reason to expect the presence of a positive correlation between the level of political complexity and

[12] With a considerable degree of oversimplification it can be said that in this case the system singular point (center) can be considered as that point around which the system rotation takes place in the phase space during the cycles.

[13] Within real ecological systems this may be observed, for example, if the predators' size decreases due to some evolutionary pressures. Indeed, if in order to support its survival a predator needs just one prey animal a day (instead of, say, five analogous prey animals), then the same prey population may support reproduction of a much larger predator population.

warfare frequency. Our cross-cultural test employing the same database has shown that such a correlation is actually observed (see Diagram 4.13):

Diagram 4.13. Correlation between Political Complexity Level and Warfare Frequency, for the Standard Cross-Cultural Sample, scatterplot with a fitted regression line



NOTES: ***Rho* = + 0.262, *p* = 0.002**. Sources and codes for the warfare frequency index are described in notes to Diagram 4.1. The number of supracommunal political integration levels has been determined on the basis of the variable JURISDICTIONAL HIERARCHY BEYOND LOCAL COMMUNITY (Murdock 1967, 1985; Murdock *et al.* 1999–2000; STDS 2002: file stds10.sav [v237]).

Political centralization, however, is only one of several relevant millennial trends. No less relevant, for us here, is a trend already considered by us in detail earlier (Korotayev, Malkov, and Khaltourina 2006): the long-term increase in carrying capacity that has been driven by the millennial trend of technological growth.

Is it possible to use the Lotka – Volterra equations to model how this long-term trend would be expected to affect the warfare's frequency? Let us recollect the basic model of population dynamics developed by Verhulst (1838):

$$\frac{dN}{dt} = rN(1 - \frac{N}{K}), \qquad (4.2)$$

where N is population, K is carrying capacity, and r is the intrinsic population growth rate in the absence of any resource limitations.

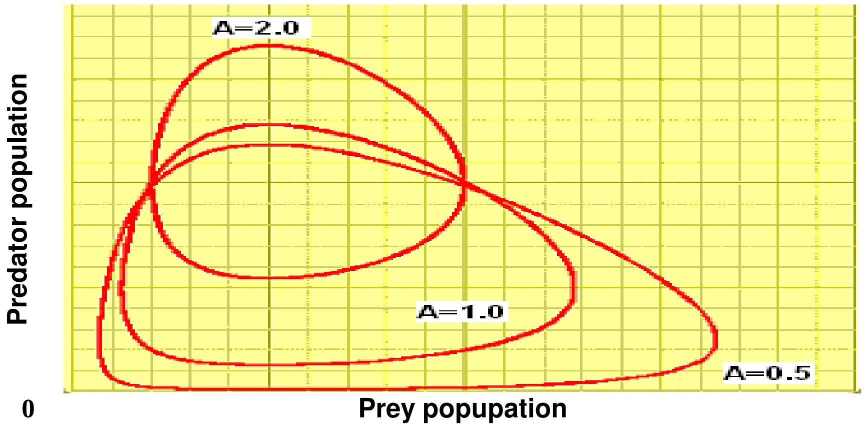
According to this model, an increase in carrying capacity, in the absence of predators, will lead (*ceteris paribus*) to an increase in the relative growth rate of

[14] As we shall see below, for modern cultures the Lotka – Volterra model turns out to be inapplicable (at least in the context that is of interest for us here).

the prey population. Hence, the influence of carrying capacity growth on military-demographic dynamics can be easily modeled by increasing the value of coefficient *A* in the Lotka – Volterra model. As this coefficient is increased, what will happen with the predator population dynamics?

Ceteris paribus (that is, with the same values for initial prey and predator populations, as well as for coefficients *B*, *C*, and *D*), the increase in the value of coefficient *A* will also lead to un upward drift of the system singular point (center) in the phase space, as we have already observed for a decrease in coefficient *B* (see Diagram 4.14):

Diagram 4.14. Drift of the "Predator – Prey" System Center with the Increase in Lotka – Volterra Coefficient *A* Value from 0.5 to 2.0



NOTE: The value of coefficients *B*, *C*, and *D* was taken as 1.0 for all three simulations. The initial values of prey and predator populations were also identical for all three simulations.

In this case too, the upward singular point (center) drift within the phase space implies that the predator population increases for all the cycle phases; thus, the average predator population increases for any given year of the cycle.[15]

Thus, for traditional societies[16] we have definite grounds to expect a positive correlation between the technologically determined carrying capacity and warfare frequency. To test this hypothesis cross-culturally we can compare warfare frequencies in pre-agricultural societies with those in cultures practicing casual,

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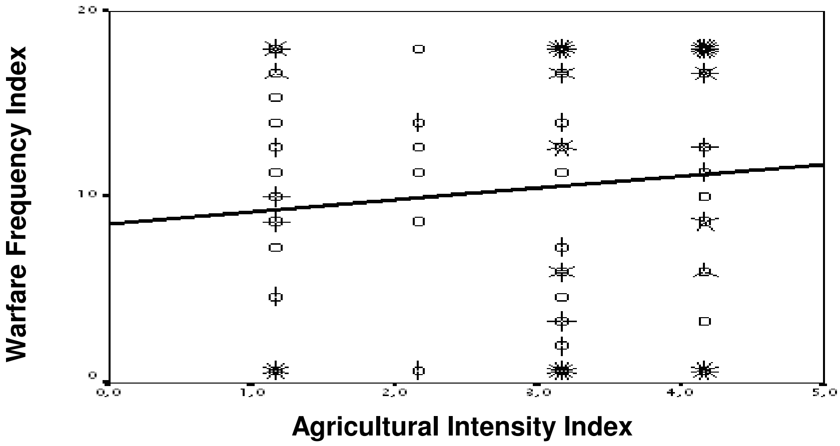
[15] It is easy to understand why such a dynamics will be observed in actual ecological systems. Indeed, if the carrying capacity increased *n* times with respect to the prey population, it would mean that the respective zone could support *n* times more prey animals, and, hence, it would tend to be able to support *n* times more predators.

[16] In modern (and even "protomodern") societies, as we shall see this below, the technologically determined increase in carrying capacity tends to decrease rather than to increase warfare frequency.

extensive, and intensive agriculture. The transition to agriculture and its intensification was accompanied by a radical increase in the carrying capacity. Therefore our hypothesis may be operationalized in the following way: the highest warfare frequency should be observed among the intensive agriculturalists, the frequency should be significantly lower among the extensive agriculturalists, and so on. Our cross-cultural test employing the same database indicates that such a correlation is actually observed (see Diagram 4.15):

Diagram 4.15. Correlation between Intensity of Subsistence Economy and Warfare Frequency, for the Standard Cross-Cultural Sample, scatterplot with a fitted regression line



NOTES: ***Rho* = + 0.136, *p* = 0.044** (1-tailed). Sources and codes for warfare frequency index are described in notes to Diagram 4.1. The intensity of subsistence economy has been determined on the basis of the variable INTENSITY OF CULTIVATION (Murdock 1967, 1985; Murdock *et al.* 1999–2000; STDS 2002: file stds10.sav [v232]).

As we see, our cross-cultural test has detected the presence of a statistically significant correlation in the predicted direction. It may be no coincidence, moreover, that in the present test the correlation is only about half as strong as in the previous test (see Diagram 4.13). The point is that the growth of political complexity tends to be accompanied by the growth of carrying capacity. In fact, these variables are dynamically related with each other. The intensification of subsistence economy creates powerful stimuli towards the growth of political complexity (of course, the presence of such stimuli does not always lead to the actual growth of political complexity, but it is by no means infrequently that it does so). On the other hand, the growth of political complexity creates powerful stimuli towards the intensification of the subsistence economy (see, *e.g.*, Korotayev 1991). As a result, we observe a rather pronounced correlation between the intensity of subsistence economy and political complexity (see Table 4.1):

Table 4.1. Correlation between Intensity of Subsistence Economy and Political Complexity

Subsistence Economy Intensity Index	Political Complexity Index = Number of Political Integration Levels over Community					*Total*
	0 (independent communities)	1 (simple chiefdoms[17])	2 (complex chiefdoms[18])	3 (simple states[19])	≥ 4 (complex states/empires)	
1 (agriculture is absent)	34 *81%*	8 *19%*	0 *0%*	0 *0%*	0 *0%*	42 *100%*
2 (incipient agriculture)	5 *50%*	3 *30%*	0 *0%*	2 *20%*	0 *0%*	10 *100%*
3 (extensive agriculture)	20 *37%*	21 *38.9%*	11 *20.4%*	2 *3.7%*	0 *0%*	54 *100%*
4 (intensive agriculture)	8 *25.8%*	5 *16.1%*	5 *16.1%*	9 *29.0%*	4 *12.9%*	31 *100%*
5 (intensive irrigated agriculture)	6 *20.7%*	5 *17.2%*	4 *13.8%*	6 *20.7%*	8 *27.6%*	29 *100%*
Total	73	42	20	19	12	166

NOTE: ***Rho* = + 0.540,** ***p* = 0,00000000000006**
Gamma = + 0.612, ***p* < 0,00000000000000001**

As we see, all the above mentioned advances in subsistence technology correlate rather strongly with the growth of political complexity.

Consistent with this is the fact that preagricultural societies appear almost never to have been organized as states; intensive agriculturalists, conversely, had, as their most typical form of political organization, precisely the state.

As we see from Table 4.1, a certain degree of subsistence economy intensification is an absolutely necessary condition for the formation of a complex political organization; however, even a very high level of subsistence economy intensification is not a sufficient condition for the development of very complex forms of political organization, such as the state and its alternatives.

On the other hand, as we have seen in earlier chapters, the growth of political complexity can be regarded in itself as one of the possible ways to increase the carrying capacity.

[17] Or alternative forms of political organization of an equivalent complexity level.
[18] Or alternative forms of political organization of an equivalent complexity level.
[19] Or alternative forms of political organization of an equivalent complexity level (on the forms of political organization that are alternative to chiefdoms and states see, *e.g.*, Bondarenko 2001; Kradin *et al.* 2000; Kradin 2001; Bondarenko and Korotayev 2000, 2002; Bondarenko, Grinin, and Korotayev 2002; Grinin 2003; Grinin *et al.* 2004 *etc.*).

In this regard it is remarkable that more politically complex societies tend to have higher population density than societies with the same subsistence economy intensity, but with a simple political organization (see, *e.g.*, Table 4.2):

Table 4.2. Correlation between Political Complexity and Population Density (for societies with subsistence economy based on intensive irrigated agriculture)

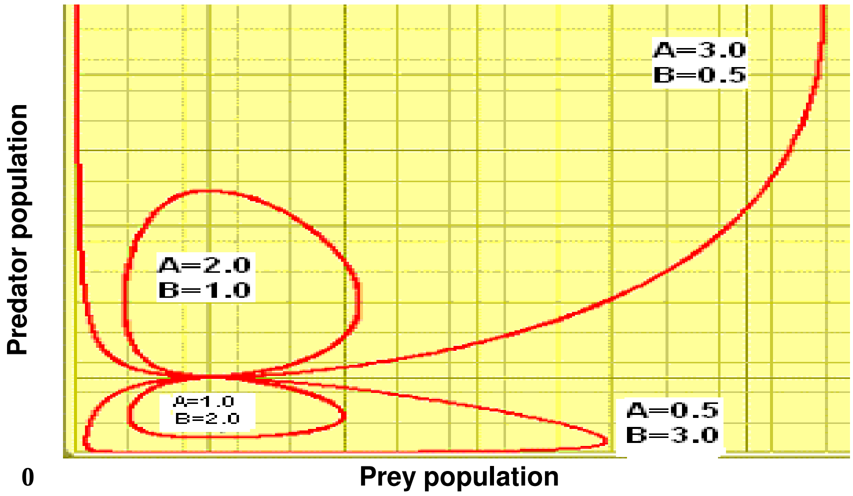
Population Density	Political Complexity Index = Number of Political Integration Levels over Community					*Total*
	0 (independent communities)	1 (simple chiefdoms)	2 (complex chiefdoms)	3 (simple states)	≥ 4 (complex states/empires)	
< 1 person per 5 sq. miles	1	1	1	0	0	3
1–5 persons per sq. mile	1	3	0	0	0	4
6–25 persons per sq. mile	0	0	0	0	2	2
26–100 persons per sq. mile	2	0	0	1	0	3
101–500 persons per sq. mile	1	1	1	1	1	5
> 500 persons per sq. mile	0	0	2	4	5	11
Итого	5	5	4	6	8	28

NOTE: ***Rho* = + 0.53, *p* = 0,00002**

Though a higher level of subsistence economy intensity does not necessarily imply the presence of a radically more complex political organization, a radical growth of political complexity is almost inevitably accompanied (at least in a long-term perspective) by a radical increase in carrying capacity.[20] This appears to explain, to a considerable degree, why warfare frequency correlates with political complexity more strongly than it does with subsistence economy intensity. Indeed, within the Lotka – Volterra model the highest predator population will be observed if we increase the value of coefficient *A*, while simultaneously decreasing coefficient *B* (which in social reality would correspond to the simultaneous growth of carrying capacity and decrease of warfare "lethality"), see Diagram 4.16:

[20] It seems necessary to stress again that these two variables are connected with each other by a mutual positive dynamic relationship; thus it appears to be incorrect to define either of them as independent, while considering the other as unequivocally dependent.

Diagram 4.16. Drift of the "Prey – Predator" System Center with the Simultaneous Increase in Lotka – Volterra Coefficient *A* Value from 0.5 to 3.0 and Decrease in Coefficient *B* Value from 3.0 to 0.5



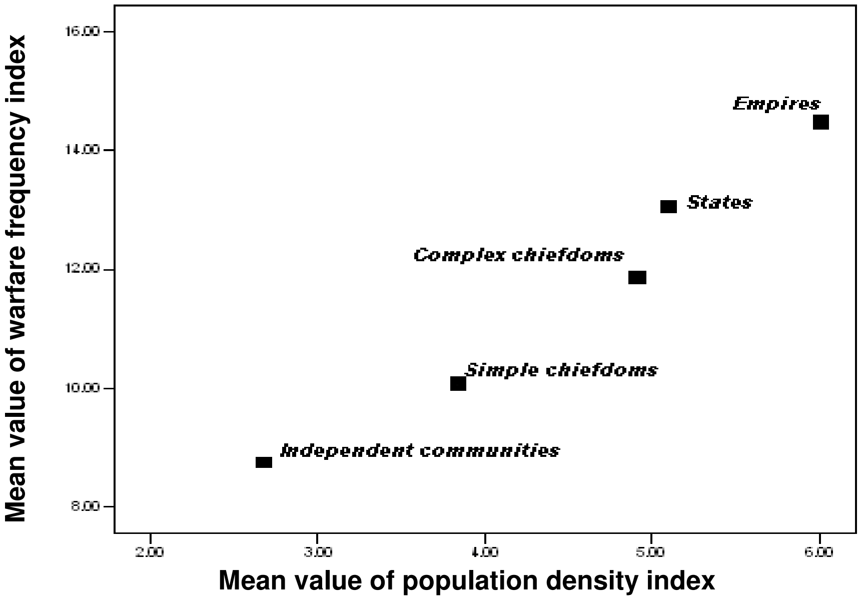
NOTE: The value of coefficients *C* and *D* was taken as 1.0 for all three simulations. The initial values of prey and predator populations were also identical for all three simulations.

Subsistence economy intensification will be inevitably accompanied only by carrying capacity growth (*i.e.*, by "increase in the value of coefficient *A*"), whereas a radical increase in political complexity is almost inevitably accompanied simultaneously both by carrying capacity growth (*i.e.*, by "increase in the value of coefficient *A*") and by decrease of warfare "lethality" (*i.e.*, by the "decrease of the value of coefficient *B*"); this appears to account for political complexity's correlating more strongly with warfare frequency than does subsistence economy intensity.

Throughout human history we observe a long-term trend towards (1) the growth of carrying capacity, closely associated with trends towards (2) increase in population density, and (3) growth of political complexity. As we have seen above, at least trends (1) and (3) should correlate with the growth of warfare frequency. Thus, should we not expect that in the long-term perspective we should also observe a rather strong correlation between population density and warfare frequency? Of course we should.

However, in order to detect this correlation we should alter the unit of comparison and compare the mean values of population density and warfare frequency that are typical for societies with different levels of political complexity (see Diagram 4.17):

Diagram 4.17. Correlation between Population Density and Warfare Frequency, for cultures with different levels of political complexity



NOTE: $r = +0.984$, $\alpha = 0.002$. Sources and codes for the warfare frequency index are described in notes to Diagram 4.1. The diagram's five points can be interpreted as roughly corresponding to the positions of the most typical singular points (centers) of military-demographic cycles for respective types of cultures.

Thus, our hypothesis has been supported. Indeed, the tightly interconnected millennial trends towards the development of subsistence technologies, growth of political complexity, carrying capacity, and population density[21] were accompanied by a pronounced increase in frequency of warfare (which was, incidentally, the principal means through which the growth of political complexity was taking place [see, *e.g.*, Carneiro 1970, 1981, 1987, 1991, 2000a, 2000b; Graber 1995 *etc.*]). This trend could finally result in such situations as that described, for example, for Ancient Rome, where "the doors of the Janus Temple (that according to the Roman traditions should have been kept open when the Roman polity was in the state of war) remained open for more than 200 years" (Knabe 1983: 80).

It appears necessary to stress that warfare frequency correlates positively with population density only when technological growth fails, for a considerable

[21] For an interesting mathematical model describing the relationship between population density and political complexity see Graber 1995.

period, to raise carrying capacity as rapidly as population is growing. After the carrying capacity starts growing substantially faster than population, the demographic growth is no longer accompanied by increase in population pressure, and warfare, as described in a mathematical model presented at the end of this chapter, begins to decline.

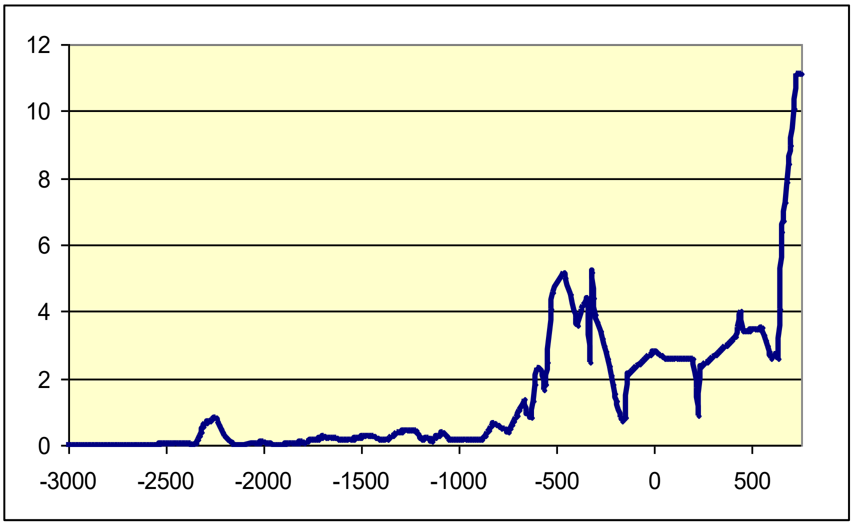
Thus, our research has confirmed that, notwithstanding recent arguments to the contrary, population density was a major determinant of warfare frequency in pre-industrial societies. However, the relationship between the two variables is dynamic, and could only be adequately described by nonlinear dynamic models. Hence, we confront a rather paradoxical situation. On the one hand, we observe a millennial trend leading to the growth of both population density and warfare frequency. As a result, from a long-term perspective, we observe a very strong positive correlation between these two variables. But on the other hand, we also observe secular demographic-warfare cycles, which produce negative correlations both for individual cultures and for subsamples of cultures with similar levels of technological and/or political development. So finally, if we make a straightforward cross-cultural test of the linear relationship between the two variables using a world-wide sample including cultures with all levels of technological and political development, we do not find any significant correlation at all. However it appears that hiding behind this "non-correlation" is the presence of an extremely strong and significant dynamic non-linear relationship.

Models of the type analyzed in the previous chapters could be used as a basis for development of a new generation of models accounting both for "secular cycles" and "millennial trends". In order to do this, we suggest altering some basic assumptions of the earlier generations of demographic cycle models, specifically, their assumptions that both the carrying capacity of land and the polity size are constant. Carrying capacity, cultural complexity, and polity size, for example, far from being constant, are nothing less than the variables with pronounced trend dynamics that the new generation of models needs to account for. Demographic cycle models account at present only for cyclical dynamics; the new modeling should be able to interconnect trend with phase dynamics.

For example, there are both theoretical and empirical grounds to maintain that the carrying capacity not only experienced a long-term upward hyperbolic trend (as has been analyzed in detail in Korotayev, Malkov, and Khaltourina 2006), but also that the innovations contributing to this trend occurred in particular phases of demographic-political cycles. Incentives created by the relative abundance of resources in the initial upward growth phases of agrarian state demographic-political cycles tend to be insufficient to create the innovations leading to the rise of the carrying capacity (these phases, however, were also very important, since during them there were strong incentives for the innovations that eventuated in the rise of the productivity of labor). Rather, innovations raising the carrying capacity tended to occur during intermediate growth phases before the demographic collapse phase. While such innovations usually acted only to delay demographic collapses, they secured the existence of a very important upward trend, which could be accounted for, to some extent, as a by-product of sociodemographic cycle dynamics.

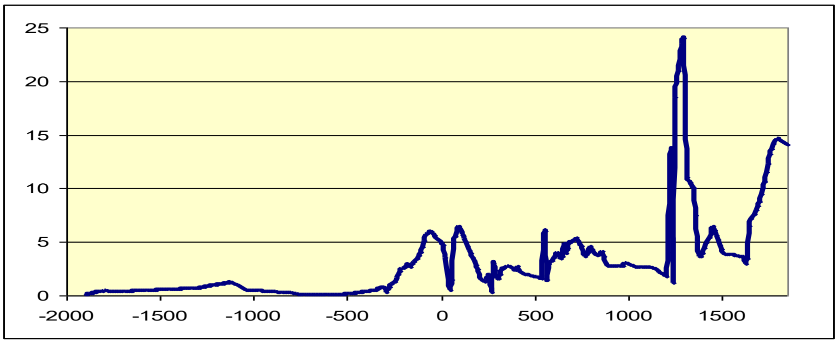
Another trend is the one towards larger polity sizes (see Diagrams 4.18 and 4.19 for West and East Asia).

Diagram 4.18. Growth Trend of Largest State/Empire Territory Size (millions of square km) in West Asian/Mesopotamia Centered System, 3000 BCE – 750 CE



SOURCES: Taagepera 1968; 1978a; 1978b; 1979; 1997:

Diagram 4.19. Growth Trend of Largest State/Empire Territory (millions of square km) in the East Asian/China Centered Regional System, 1900 BCE – 1850 CE

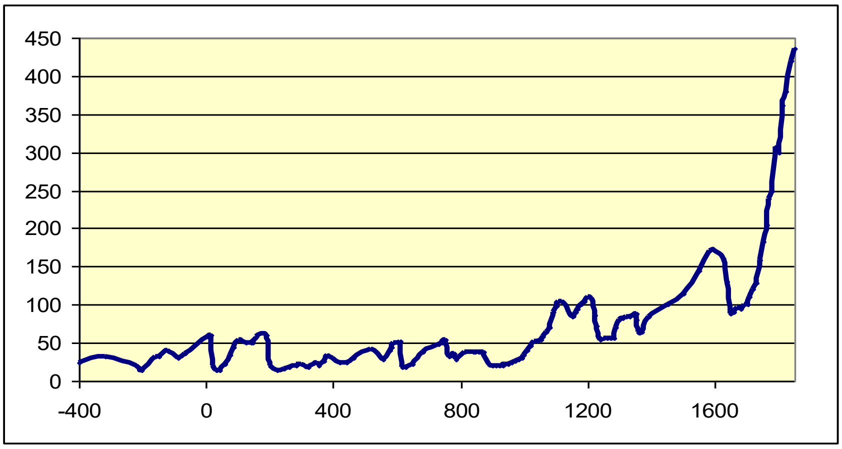


SOURCES: Taagepera 1968; 1978a; 1978b; 1979; 1997.

This trend seems to be accounted by the fact that infrastructures created by empires do not usually disappear entirely with the collapse of the systems that created them. Hence, new empires frequently do not have to build imperial infrastructures entirely anew and can rely to a considerable extent on preexisting infrastructures, making it more likely that later empires will outgrow earlier ones.

It is revealing to compare the diagram above with the one depicting population dynamics of China during the same period (see Diagram 4.20):

Diagram 4.20. Chinese Population Dynamics (in millions), 400 BCE – 1850 CE



NOTE: The diagram reproduces estimates surveyed above in Chapter 2

While comparing Diagrams 4.19 and 4.20 it is difficult not to notice a rather close fit between demographic cycles and cycles of territorial expansion/contraction. We do not think this is a coincidence.

What theoretical expectations might we have for the relationship between phases of these cycles? It has turned out that a considerable number of relevant theoretical predictions can be generated by Turchin's demographic-fiscal model (Turchin 2003: 121–7), based on Goldstone (1991). Let us recollect the main logic of this model, which can be outlined as follows:

During the initial phase of a demographic cycle we observe relatively high levels of per capita production and consumption, leading not only to relatively high population growth rates, but also to relatively high rates of surplus production. As a result, during this phase the population can afford paying taxes without great problems, the taxes are quite easily collectable, and the population growth is accompanied by growth of state revenues. During the intermediate phase, the increasing overpopulation leads to decrease of per capita production and consumption levels, it becomes more and more difficult to collect taxes, and state revenues stop growing, whereas state expenditures grow due to the growth of the population controlled by the state. As a result, during this phase the state starts experiencing considerable fiscal difficulty. During the final pre-collapse phases the overpopulation leads to further decrease of per capita production, the surplus production further decreases, and state revenues shrink, whereas the state requires more and more resources to control the population (which is still growing, though at lower and lower rates). Eventually this leads to state breakdown and demographic collapse, after which a new demographic cycle begins.

What kind of territorial expansion/contraction pattern would be generated by such demographic-fiscal dynamics? During the initial phase state revenues are high and continue to grow, making it possible for a state to support large armies and to undertake active territorial expansion. Note that this is only valid for unipolar regional systems, *i.e.*, systems with a single strong state. In multipolar regional systems comprising a few equally strong states we can only expect that the composite states will try to undertake attempts at territorial expansion. However, there are naturally no guarantees that the attempts of any particular state will be successful. What is more, within a fairly balanced multipolar system such attempts undertaken by a few states could result in a stalemate, as a result of which none of the participant states would enjoy considerable territorial gains.

During the intermediate phase the state starts experiencing fiscal problems, its ability to support large and effective armies decreases. Thus, we have grounds to expect that during this phase imperial territorial expansion will slow down.

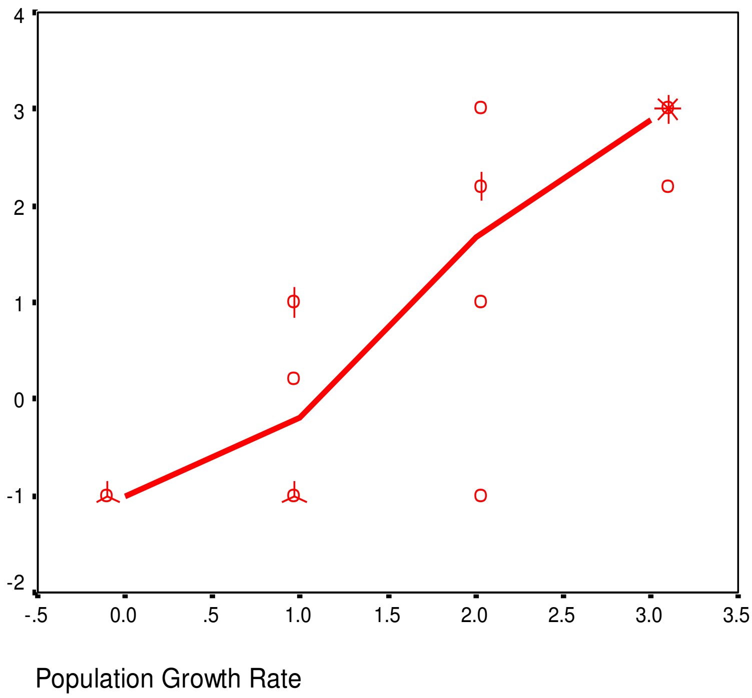
During the final pre-collapse phase state revenues considerably decrease, which leads to a considerable decrease of the size and effectiveness of military forces supported by the state. Hence, we have grounds to expect that during this phase imperial territorial expansion will stop. What is more, during this phase the state territory is likely to start contracting.

To test these predictions we have used Taagapera's database on historical dynamics of empire sizes (Taagepera 1968; 1978a; 1978b; 1979; 1997), as well as Nefedov's (1999b, 1999d, 2000a, 2001b, 2003) and Turchin's (2003b) data on population and consumption dynamics.[22]

The first (and the least counterintuitive) prediction tested by us is that the phases of relatively rapid population growth should correlate with phases of relatively rapid territorial expansion.

The test has supported this hypothesis: the correlation has turned out to be in the predicted direction, very strong, and significant beyond any doubt (see Diagram 4.21 and Table 4.3):

Diagram 4.21. Population Growth Rate × Territorial Expansion/Aggressive External Warfare (scatterplot with fitted Lowess line)



[22] Note that in both cases we are not really dealing with a sample, but rather with the general population of all cases, for which empirical data are available.

Table 4.3. Population Growth Rate (direct and indirect evidence) × Territorial Expansion/Aggressive External Warfare

		Territorial Expansion/Aggressive External Warfare					Total
		-1 (mostly defensive warfare)	*0 (almost absent)*	*1 (relatively low)*	*2 (intermediate)*	*3 (relatively high)*	
Population Growth Rate (direct and indirect evidence)	*0 (stagnation)*	**3**[23]					3
	1 (relatively low)	**3**[24]	**1**[25]	**2**[26]			6
	2 (intermediate)	**1**[27]		**1**[28]	**2**[29]	**1**[30]	5
	3 (relatively high)				**1**[31]	**8**[32]	9
Total		7	1	3	3	9	23

NOTES: *For all cases: Tau-b* = + 0.81, $p < 0.00000000000000001$; *Rho* = + 0.83, $p = 0.00000002$. *For cases with direct evidence on population growth rate (all Chinese): Tau-b* = + 0.79, $p < 0.00000000000000001$; *Rho* = + 0.87, $p = .000003$. *For non-Chinese cases (Roman, direct evidence; Babylonian, indirect evidence):* no correlation coefficient can be computed due to the small number of cases, but the contrastive periods for the Roman and Babylonian cases are consistent with the hypothesis.

Note, however, that for the direct test of this hypothesis we had to rely almost exclusively on the Chinese data, as East Asia is the only region (and the only

[23] Roman Empire 120 – 200 CE, *Western Han 40 BCE – 10 CE*, Eastern Han 105 – 157 CE (Roman type is used for cases for which direct evidence is available for both variables, and *italics* where evidence is indirect for one or both variables).
[24] *Babylonia 556 – 539 BCE*, T'ang 733 – 754, Ming 1450 – 1620.
[25] Qing 1800 – 1830.
[26] *Moghol Empire 1670 – 1690*, Roman Empire 50 – 120 CE.
[27] Sung 1000 – 1066.
[28] Ming 1410 – 1450.
[29] *Moghol Empire 1620 – 1670*, Western Han 110 – 40 BCE.
[30] Qing 1720 – 1750.
[31] Qing 1750 – 1800.
[32] *Babylonia 605 – 562 BCE, Moghol Empire 1560 – 1620*, Roman Empire 40 BCE – 50 CE, Western Han 180 – 110 BCE, Eastern Han 57 – 105 CE, T'ang 627 – 733, Sung 960 – 1000, Ming 1360 – 1410.

unipolar region) for which we have direct data on historical population dynamics. On the other hand, it has proven possible to collect sufficient extra-Chinese data to test our next hypothesis, namely, the one linking relative per capita consumption levels and territorial expansion/contraction. What are our theoretical predictions in this case?

To start with, the demographic cycle models predict that the relatively fast population growth should correlate with relatively high consumption levels. Our empirical test of this assumption has confirmed its validity (see Diagram 4.22 and Table 4.4):

Diagram 4.22. Relative Consumption Rate × Territorial Expansion/Aggressive External Warfare (scatterplot with fitted Lowess line)

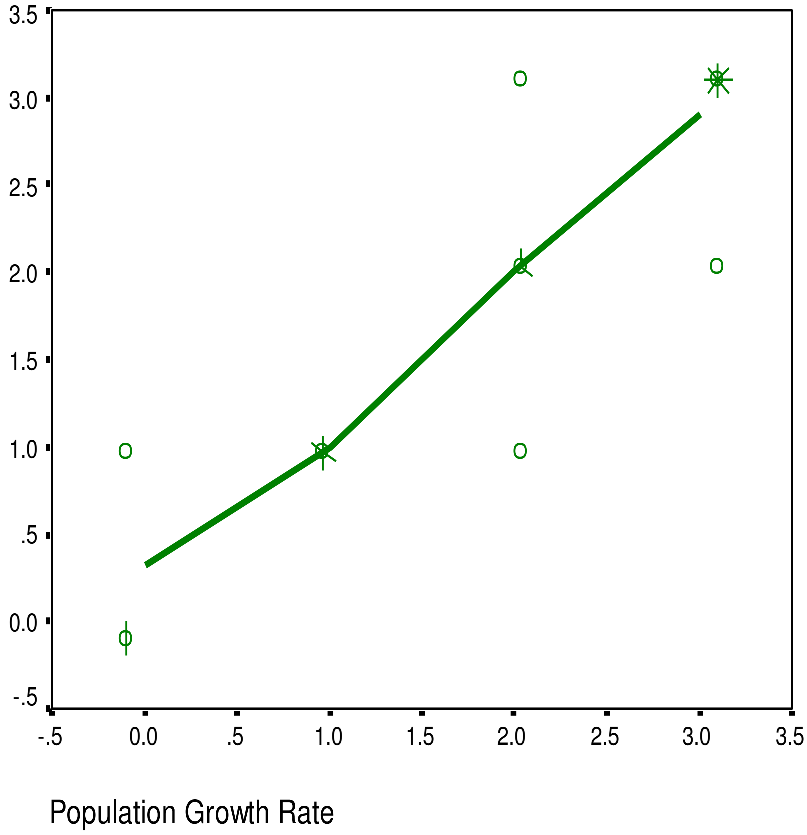


Table 4.4. Population Growth Rate (direct and indirect evidence) × Relative Consumption Rate (direct and indirect evidence)

		Relative Consumption Rate (direct and indirect evidence)				**Total**
		0 (very low)	*1 (relatively low)*	*2 (intermediate)*	*3 (relatively high)*	
Population Growth Rate (direct and indirect evidence)	*0 (stagnation)*	**2**[33]	**1**[34]			3
	1 (relatively low)		**6**[35]			6
	2 (intermediate)		**1**[36]	**3**[37]	**1**[38]	5
	3 (relatively high)			**1**[39]	**8**[40]	9
Total		2	8	4	9	23

For all cases: *Tau-b* = + 0.88, $p < 0.00000000000000001$
Rho = + 0.92, $p = 0.0000000009$
For cases with direct evidence on population growth rate:
Tau-b = + 0.85, $p = 0.000004$
Rho = + 0.92, $p = 0.0000000009$

Against the background of our first test, this of course suggests that relatively high consumption levels should correlate positively with relatively rapid territorial expansion. Note that as the consumption rates are usually measured through the real wages of unskilled workers (the amount of staple food an unskilled worker could buy from daily wages), the operationalization of this hypothesis may sound especially counterintuitive: we claim that if we know the relative real wages of unskilled workers, at least in the center of a unipolar system, we can predict with a very high degree of confidence whether the respective empire experienced a relatively rapid expansion, expanded slowly, or contracted. In fact, there is nothing mysterious in this relationship. Relatively high real wages imply

[33] Roman Empire 120 – 200 CE, *Western Han 40 BCE – 10 CE*.
[34] Eastern Han 105 – 157 CE.
[35] *Babylonia 556 – 539 BCE*, Roman Empire 50 – 120 CE, *Moghol Empire 1670 – 1690*, T'ang 733 – 754, Ming 1450 – 1620, Qing 1800 – 1830.
[36] *Western Han 110 – 40 BCE*.
[37] *Moghol Empire 1620 – 1670*, Sung 1000 – 1066, Ming 1410 – 1450.
[38] Qing 1720 – 1750.
[39] Qing 1750 – 1800.
[40] *Babylonia 605 – 562 BCE*, Roman Empire 40 BCE – 50 CE, *Moghol Empire 1560 – 1620*, *Western Han 180 – 110 BCE*, Eeastern Han 57 – 105 CE, T'ang 627 – 733, Sung 960 – 1000, Ming 1360 – 1410.

that labor is a scarce resource, hence, there is no overpopulation; the population, being well provided with resources, rapidly grows, producing large surpluses; and the state has high and growing revenues with which to support a large, effective army and to undertake rapid territorial expansion. On the other hand, relatively low real wages imply that labor is overabundant, hence, there is overpopulation; the population, being insufficiently provided with resources, grows slowly, producing almost no surplus, and the state having low and shrinking revenues is unable to support a large, effective army and to undertake a rapid territorial expansion; indeed, it may fail even to organize adequate defense of territories under its control.

The test has supported this hypothesis: the correlation has turned out to be in the predicted direction, very strong, and significant beyond any doubt (see Diagram 4.23 and Table 4.5):

Diagram 4.23. Relative Consumption Rate × Territorial Expansion/Aggressive External Warfare

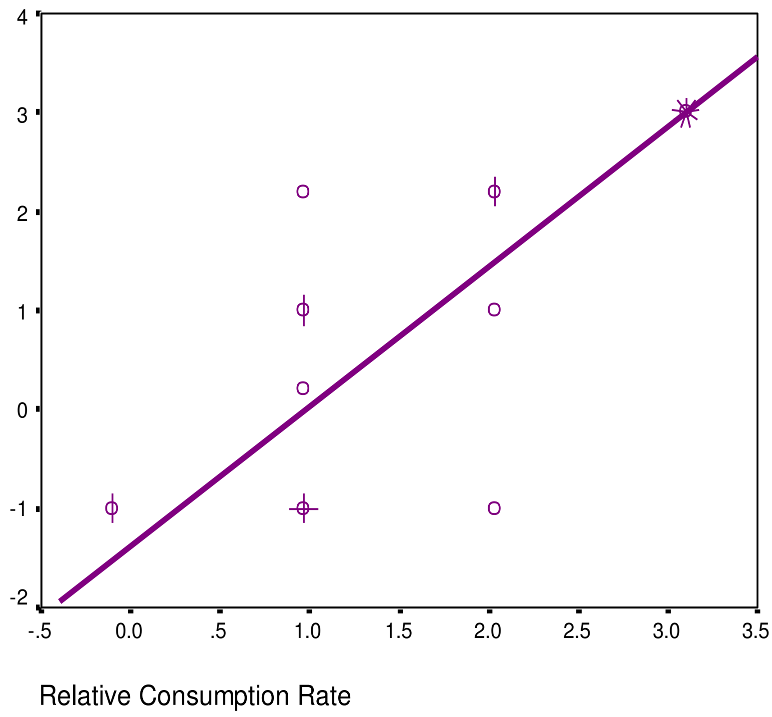


Table 4.5. Relative Consumption Rate (direct and indirect evidence) × Territorial Expansion/Aggressive External Warfare

		Territorial Expansion/Aggressive External Warfare					**Total**
		-1 (mostly defensive warfare)	*0 (almost absent)*	*1 (relatively low)*	*2 (intermediate)*	*3 (relatively high)*	
Relative Consumption Rate (direct and indirect evidence)	*0 (very low)*	**2**[41]					2
	1 (relatively low)	**4**[42]	**1**[43]	**2**[44]	**1**[45]		8
	2 (intermediate)	**1**[46]		**1**[47]	**2**[48]		4
	3relatively high					**9**[49]	9
Total		7	1	3	3	9	23

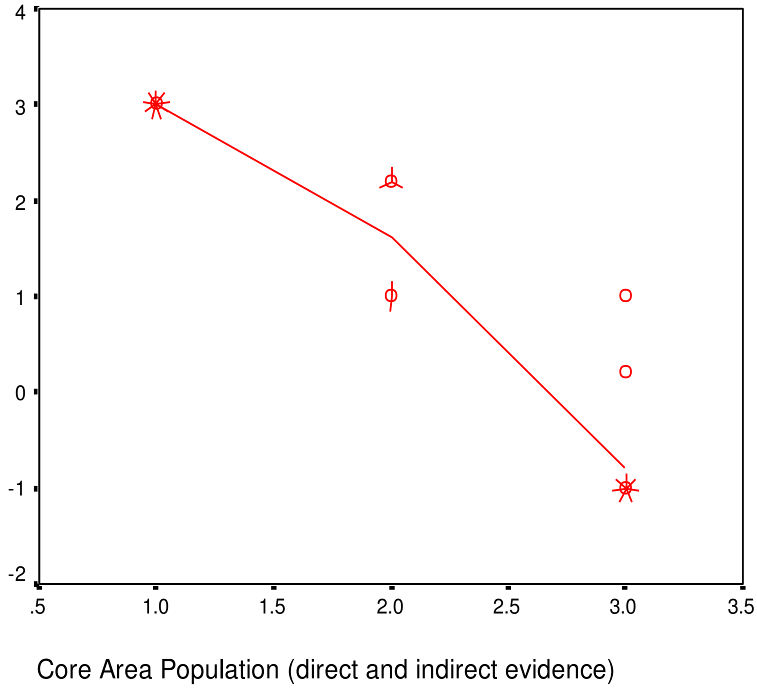
For all cases: *Tau-b* = + 0.83, *p* < 0.00000000000000001; *Rho* = + 0.90, *p* = 0.00000001
For cases with direct evidence on population growth rate:
Tau-b = + 0.85, *p* < 0.00000000000000001; *Rho* = + 0.91, *p* = 0.00000002
For non-Chinese cases: Tau-b = + 0.93, *p* < 0.00000000000000001; *Rho* = + 0.96, *p* = 0.0001

The population of the core area[50] is smallest during the initial phase of the demographic cycle and is highest during the final pre-collapse phase. This results

[41] Roman Empire 120 – 200 CE, *Western Han 40BCE – 10CE*.
[42] Eastern Han 105 – 157 CE, Babylonia 556 – 539 BCE, T'ang 733 – 754, Ming 1450 – 1620.
[43] Qing 1800 – 1830.
[44] Roman Empire 50 – 120, Moghol Empire 1670 – 1690.
[45] Western Han 110 – 40 BCE.
[46] Sung 1000 – 1066.
[47] Qing 1720 – 1750.
[48] Moghol Empire 1620 – 1670, Qing 1750 – 1800.
[49] Babylonia 605 – 562 BCE, Roman Empire 40 BCE – 50 CE, Moghol Empire 1560 – 1620, Western Han 180 – 110 BCE, Eeastern Han 57 – 105 CE, T'ang 627 – 733, Sung 960 – 1000, Ming 1360 – 1410, Qing 1720 – 1750.

in another counterintuitive hypothesis – the relatively higher the population of the empire core area, the lower its expansion rate. Our empirical test has supported this hypothesis too (see Diagram 4.24 and Table 4.6):

Diagram 4.24. Core Area Population × Territorial Expansion/Aggressive External Warfare



1 – low in comparison with other phases of respective cycle

2 – intermediate in comparison with other phases of respective cycle

3 – high in comparison with other phases of respective cycle

[50] The core area is defined here as the area of the central polity of a unipolar region before the start of its expansion at the beginning of a political-demographic cycle.

Table 4.6. Correlation between Core Area Population (direct and indirect evidence) and Territorial Expansion/Aggressive External Warfare

		Territorial Expansion/Aggressive External Warfare					**Total**
		-1 (mostly defensive warfare)	*0 (almost absent)*	*1 (relatively low)*	*2 (intermediate)*	*3 (relatively high)*	
Core Area Population (direct and indirect evidence)	*1 (relatively low)*					9[51]	9
	2 (intermediate)			2[52]	3[53]		5
	3 (relatively high)	7[54]	1[55]	1[56]			9
Total		7	1	3	3	9	23

NOTE: *Tau-b* = – 0.94, $p < 0.00000000000000001$; *Rho* = + 0.97, $p = 0.00000000000001$.

Hence, these findings support a point made earlier, that the structure of millennial trends cannot be adequately understood without secular cycles being taken into account. At a certain level of analysis, millennial trends appear to be virtual byproducts of the demographic cycle mechanisms, which turn out to incorporate certain trend-creating mechanisms. Demographic-political cycle models can serve as a basis for the development and testing of models accounting not only for secular cycles but also for millennial trends. In order to do this, we suggest altering the basic assumptions of earlier generations of demographic cycle models (such as that both the carrying capacity and the polity size are constant).

[51] *Babylonia 605 – 562 BCE*, Roman Empire 40 BCE – 50 CE, *Moghol Empire 1560 – 1620*, Western Han 180 – 110 BCE, Eeastern Han 57 – 105 CE, T'ang 627 – 733, Sung 960 – 1000, Ming 1360 – 1410, Qing 1720 – 1750.

[52] Roman Empire 50 – 120 CE, Ming 1410 – 1450.

[53] *Moghol Empire 1620 – 1670*, Western Han 110 – 40 BCE, Qing 1750 – 1800.

[54] *Babylonia 556 – 539 BCE*, Roman Empire 120 – 200 CE, Western Han 40 BCE – 10 CE, Eastern Han 105 – 157 CE, T'ang 733 – 754, Sung 1000 – 1066, Ming 1450 – 1620.

[55] Qing 1800 – 1830.

[56] *Moghol Empire 1670 – 1690*.

These are variables with long-term trend dynamics in the rise of carrying capacity, cultural complexity, and empire sizes that the new generation of models needs to account for.

An interesting mathematical model that describes both secular political-demographic cycles and millennial growth trends has been proposed by Komlos and Nefedov (Komlos and Nefedov 2002). However, note that irrespective of all its merits it does not describe the hyperbolic trend analyzed in the first part of our *Introduction to Social Macrodynamics* (Korotayev, Malkov, and Khaltourina 2006).

At the end of this chapter we would like to propose our own preliminary model designed to describe both secular cycles and millennial trends. We have developed it on the basis of our "secular cycle" model presented in the previous chapter, basically by adding to it Kremer's equation of technological growth:

$$\frac{dT}{dt} = aNT, \tag{0.8}$$

where T is the level of technology, N is population, and a is average technologically innovating productivity per person.

Let us remind you that actually Kremer uses here the following key assumption of the Endogenous Technological Growth theory, which we have already used above for the development of the first compact macromodel (Kuznets 1960; Grossman and Helpman 1991; Aghion and Howitt 1992, 1998; Simon 1977, 1981, 2000; Komlos and Nefedov 2002; Jones 1995, 2003, 2005 *etc.*):

> "High population spurs technological change because it increases the number of potential inventors…[57]. All else equal, each person's chance of inventing something is independent of population. Thus, in a larger population there will be proportionally more people lucky or smart enough to come up with new ideas" (Kremer 1993: 685); thus, "the growth rate of technology is proportional to total population" (Kremer 1993: 682).

We also model the "Boserupian" effect (Boserup 1965). As was shown by Boserup relative overpopulation creates additional stimuli to generate and apply carrying-capacity-of-land-raising innovations. Indeed, if land shortage is absent, such stimuli are relatively weak, whereas in conditions of relative overpopulation the introduction of such innovations becomes literally a "question of life and death" for a major part of the population, and the intensity of the generation and diffusion of the carrying capacity enhancing innovations significantly increases. In our model this effect is modeled in the following way:

---

[57] "This implication flows naturally from the nonrivalry of technology… The cost of inventing a new technology is independent of the number of people who use it. Thus, holding constant the share of resources devoted to research, an increase in population leads to an increase in technological change" (Kremer 1993: 681).

$$T_{i+1} = \begin{cases} T_i + 2aN_iT_i & \text{if } Food_i/N_i \leq 1.2 \text{ MAFR}^{58}, \quad (4.3) \\ T_i + aN_iT_i & \text{if } Food_i/N_i > 1.2 \text{ MAFR}. \quad (4.4) \end{cases}$$

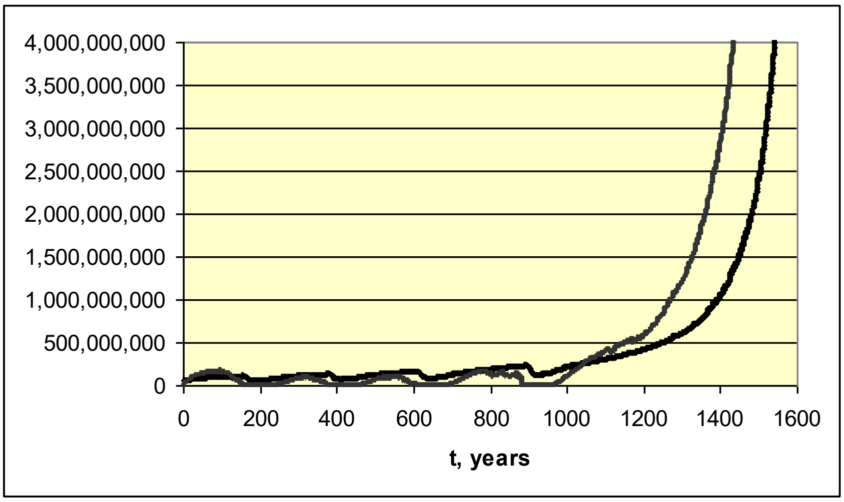
The influence of technological growth on production is taken into account through the introduction of multiplier T into (3.1), producing the following equation:

$$Harvest_i = H_0 \times random\ number_i \times T_i. \quad (4.5)$$

Thus, in our "trend-cyclical" model, the per unit yield in year i depends not only on the climatic conditions in year i (simulated with *random number*$_i$), but also on the level of subsistence technology achieved at this year.

The extension of model (3.2)-(3.4) with equations (4.3)-(4.5) alters the dynamics generated by the model in a very significant way (see Diagrams 4.25–27):

Diagram 4.25. Dynamics Generated by the Compact Trend-Cyclical Model: population (black curve, persons) and food reserves (grey curve, in MAFRs)



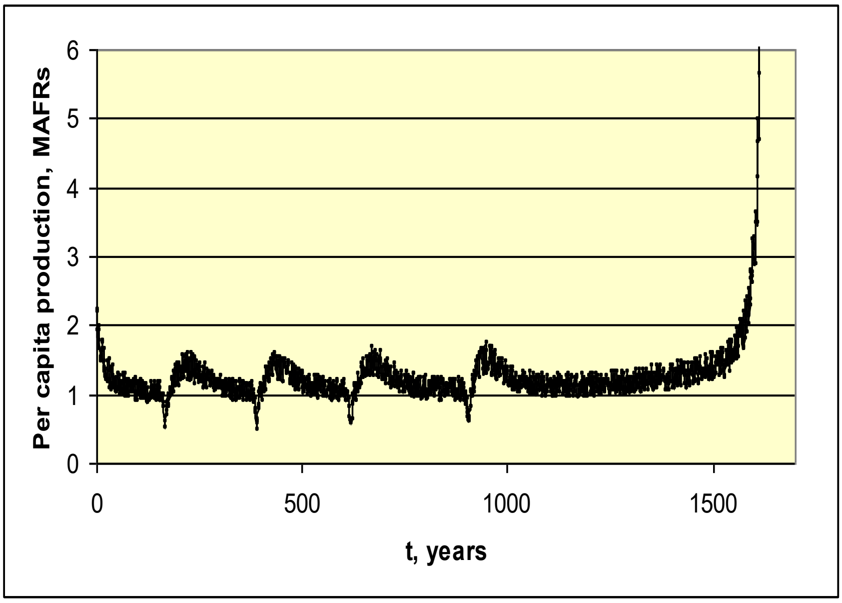
NOTE: the diagram reproduces the results of a simulation with the following values of parameters and initial conditions: N_0 = 50,000,000 peasants; A_{total} = 100,000,000 units, it is assumed that one unit produces, under average climatic conditions and initial technological level (T_0 = 1), one minimum annual food ration (MAFR), *i.e.*, an amount of food that is barely sufficient to support one

[58] Minimum annual food ration, an amount of food that is barely sufficient to support one person for one year.

person for one year, that is, H_0 = 1 MAFR per unit per year; ***random number*** range is between 0.85 and 1.15, thus *Harvest*$_i$ (per unit yield in year *i*) randomly assumes values in the range 0.85*T* to 1.15*T* MAFR per unit per year; *Food*$_{min}$ = 1 MAFR; R_0 = 1000 bandits; S_0 = 0 MAFR; α = 0.04 MAFR^{-1}; *tax* = 0.1; α_{out} = 0.1; β = 0.03; *rob* = 0.000000001; *a* (innovation productivity coefficient) = 0.000000000005.

This model describes not only cyclical, but also the hyperbolic trend dynamics. Note that it also describes the lengthening of growth phases detected in Chapter 2 for historical population dynamics in China, which was not described by our simple cyclical model. The mechanism that produces this lengthening in the model (and apparently in reality) is as follows: the later cycles are characterized by a higher technology, and, thus, higher carrying capacity and population, which, according to Kremer's technological development equation embedded into our model, produces higher rates of technological (and, thus, carrying capacity) growth. Thus, with every new cycle it takes the population more and more time to approach the carrying capacity ceiling to a critical extent; finally it "fails" to do so, the technological growth rates begin to exceed systematically the population growth rates, and population escapes from the "Malthusian trap" (see Diagram 4.26):

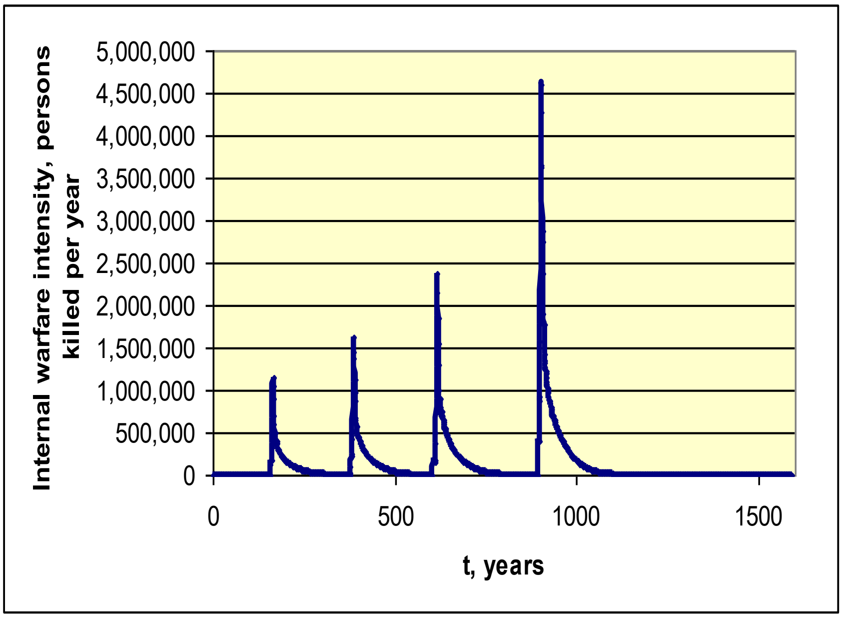
Diagram 4.26. Dynamics Generated by the Compact Trend-Cyclical Macromodel: per capita production, in MAFR



A numerical investigation of the effect of parameter values on the dynamics of our model indicates that that the main parameters that affect the period of the cycle are still the proportion of resources accumulated in counter-famine reserves (*tax*), peasant-bandit transformation rate (α_{out}), and the magnitude of climatic fluctuations (M_c). Longer cycles still obtain for higher values of *tax* and lower values of α_{out} and M_c, whereas the cycles' length becomes shorter with lower *tax*, and higher α_{out} and M_c. Thus we find again that the length of the cycles would increase with the growth of the strength of counter-famine and law-enforcement subsystems, and could be decreased by the increase in the magnitude of climatic fluctuations. Of special importance is that our numerical investigation indicates that with shorter average period of cycles a system experiences a slower technological growth, and it takes a system longer to escape from the "Malthusian trap" than with a longer average cycle period. The implications of this finding will be studied in more detail in the subsequent volume of our *Introduction to Social Macrodynamics* (Korotayev and Khaltourina 2006).

Of special interest for us here are the internal warfare dynamics described by the compact trend-cyclical model (see Diagram 4.27):

Diagram 4.27. Dynamics Generated by the Compact Trend-Cyclical Macromodel: internal warfare intensity, number of "peasants" killed by "bandits" per year



As we see, the intensity of internal warfare observed during demographic collapse phases tends to grow significantly. The mechanism that generates this effect in the model is produced by the "prey – predator" model logic whose elements are incorporated into the trend-cyclical model: a higher population of "peasants" can support a higher "bandit population" that in its turn would kill more "peasants". On the other hand, note that the population's "escape from the Malthusian trap" leads to internal warfare's "extinction": the recurrent outbreaks of internal warfare completely disappear.

Naturally, the trend-cyclical model describes historical dynamics in a more accurate way when it is extended along the lines suggested in model (0.20)-(0.14)-(0.21) (see Introduction) so that it can also describe the system's withdrawal from the blow-up regime via the demographic transition. This is done by adding to the model an equation describing literacy dynamics:

$$l_{i+1} = l_i + b \times dF_i \times l_i \times (1 - l_i), \qquad (4.6)$$

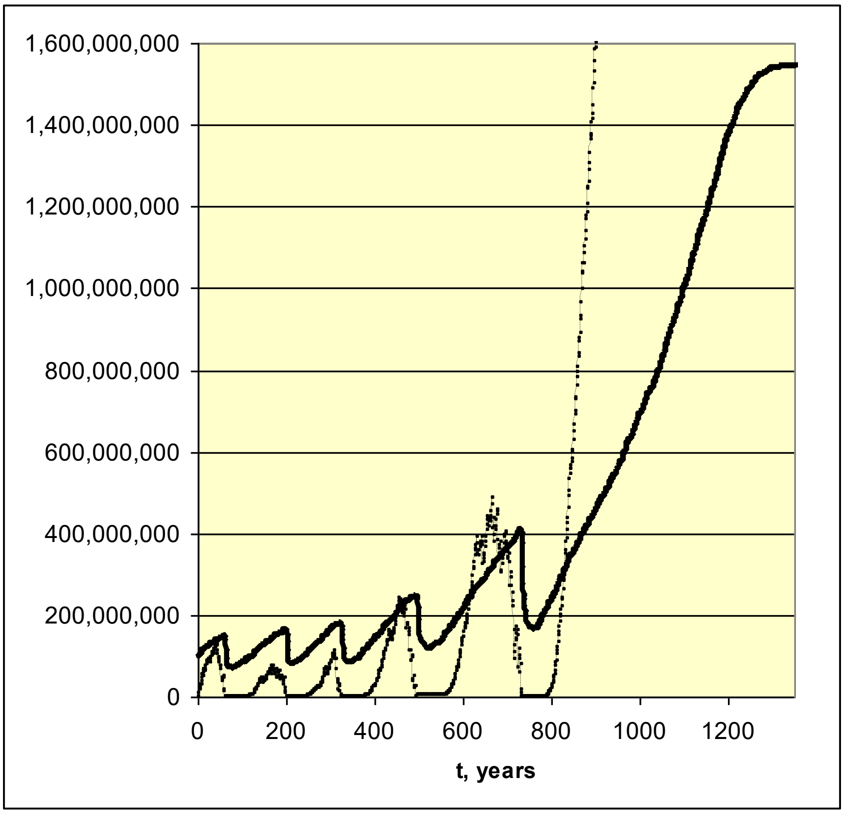
where l_i is the proportion of population that is literate in year i, dF_i is per capita surplus, and b is a constant. Of course, equation (4.6) is simply a modified version of equation (0.21), substantiated in the Introduction, as well as in Korotayev, Malkov, and Khaltourina 2006. The influence of literacy[59] on the demographic transition is expressed through the addition to (3.3) of the multiplier $(1 - l)$, which results in equation (4.7):

$$N_{i+1} = N_i \times (1 + \alpha \times dF') \times (1 - l) - dR_i - rob \times N_i \times R_i\ . \qquad (4.7)$$

Typical dynamics generated by the resulting model is presented in Diagram 4.28:

[59] And other dimensions of the human capital level that strongly correlate with literacy.

Diagram 4.28. Dynamics Generated by the Extended Trend-Cyclical Model: population (black curve, persons) and food reserves (grey curve, MAFRs)



NOTE: The diagram reproduces the results of a simulation with the following values of parameters and initial conditions: N_0 = 100,000,000 peasants; A_{total} = 150,000,000 units, it is assumed that one unit produces under average climatic conditions and initial technological level (T_0 = 1) one minimum annual food ration (MAFR), *i.e.*, an amount of food that is barely sufficient to support one person for one year, that is, H_0 = 1 MAFR per unit per year; *random number* range is between 0.65 and 1.35, thus $Harvest_i$ (per unit yield in year *i*) randomly assumes values in the range 0.65*T* to 1.35*T* MAFR per unit per year; $Food_{min}$ = 1 MAFR; R_0 = 1000 bandits; S_0 = 0 MAFR; α = 0.04 MAFR^{-1}; *tax* = 0.1; α_{out} = 0.2; β = 0.03; *rob* = 0.000000001; *a* (innovation productivity coefficient) = 0.0000000000065; *b* (literacy growth coefficient) = 0.01.

Of course, these models can be only regarded as first steps towards the development of effective models describing both secular cycles and millennial upward trend dynamics.

Conclusion[1]

Let us start the conclusion with a brief consideration of the employment of mathematical modeling in physics.

The dynamics of every physical body are influenced by a huge number of factors. Modern physics abundantly evidences this. Even if we consider such a simple case as a falling ball, we inevitably face such forces as gravitation, friction, electromagnetic forces, forces caused by pressure, by radiation, by anisotropy of medium and so on.

All these forces do have some effect on the motion of the considered body. It is a physical fact. Consequently in order to describe this motion we should construct an equation involving all these factors. Only in this case may we "guarantee" the "right" description. Moreover, even such an equation would not be quite "right", because we have not included those factors and forces which actually exist but have not been discovered yet.

It is evident that such a puristic approach and rush for precision lead to agnosticism and nothing else. Fortunately, from the physical point of view, all the processes have their characteristic time scales and their application conditions. Even if there are a great number of significant factors we can sometimes neglect all of them except the most evident one.

There are two main cases for simplification:

1. When a force caused by a selected factor is much stronger than all the other forces.

2. When a selected factor has a characteristic time scale which is adequate to the scale of the considered process, while all the other factors have significantly different time scales

The first case seems to be clear. As for the second, it is substantiated by the Tikhonov theorem (1952). It states that if there is a system of three differential equations, and if the first variable is changing very quickly, the second changes very slowly, and the third is changing with an acceptable characteristic time scale, then we can discard the first and the second equations and pay attention only to the third one. In this case the first equation must be solved as an alge-

[1] It is not necessary for those of the readers who have already read the first part of our *Introduction to Social Macrodynamics* (Korotayev, Malkov, and Khaltourina 2006) to read this conclusion (except its last paragraphs), as it was originally intended as a conclusion to both parts published as a single monograph. However, our publishers have insisted on splitting this monograph into two. Yet, this conclusion remains as relevant for *Secular Cycles and Millennial Trends* as it was for *Compact Macromodels of the World System Growth*; thus, it is reproduced at the end of this book only with minor changes.

braic equation (not as a differential one), and the second variable must be handled as a parameter.

Let us consider some extremely complicated process, for example, photosynthesis. Within this process characteristic time scales (in seconds) are as follows:

1. Light absorption: ~ 0.000000000000001.
2. Reaction of charge separation: ~ 0.000000000001.
3. Electron transport: ~ 0.0000000001.
4. Carbon fixation: ~ 1–10.
5. Transport of nutrients: ~ 100–1000.
6. Plant growth: ~ 10000–100000.

Such a spread in scales allows constructing rather simple and valid models for each process without taking all the other processes into consideration. Each time scale has its own laws and is described by equations that are limited by the corresponding conditions. If the system exceeds the limits of respective scale, its behavior will change, and the equations will also change. It is not a defect of the description – it is just a transition from one regime to another.

For example, solid bodies can be described perfectly by solid body models employing respective equations and sets of laws of motion (*e.g.*, the mechanics of rigid bodies); but increasing the temperature will cause melting, and the same body will be transformed into a liquid, which must be described by absolutely different sets of laws (*e.g.*, hydrodynamics). Finally, the same body could be transformed into a gas that obeys another set of laws (*e.g.*, Boyle's law, *etc.*)

It may look like a mystification that the same body may obey different laws and be described by different equations when temperature changes slightly (*e.g.*, from 95ºC to 105ºC)! But this is a fact. Moreover, from the microscopic point of view, all these laws originate from microinteraction of molecules, which remains the same for solid bodies, liquids, and gases. But from the point of view of macroprocesses, macrobehavior is different and the respective equations are also different. So there is nothing abnormal in the dynamics of a complex system could have phase transitions and sudden changes of regimes.

For every change in physics there are always limitations that modify the law of change in the neighborhood of some limit. Examples of such limitations are absolute zero of temperature and velocity of light. If temperature is high enough or, respectively, velocity is small, then classical laws work perfectly, but if temperature is close to absolute zero or velocity is close to the velocity of light, behavior may change incredibly. Such effects as superconductivity or space-time distortion may be observed.

As for demographic growth, there are a number of limitations, each of them having its characteristic scales and applicability conditions. Analyzing the system we can define some of these limitations.

Growth is limited by:

1. RESOURCE limitations:

1.1. Starvation – if there is no food (or other resources essential for vital functions) there must be not growth, but collapse;
time scale ~ 0.1–1 year;
conditions: RESOURCE SHORTAGE.

This is a strong limitation and it works inevitably.

1.2. Technological – technology may support a limited number of workers;
time scale ~ 10–100 years;
conditions: TECHNOLOGY IS "LOWER" THAN POPULATION.

This is a relatively rapid process, which causes political-demographic cycles discussed in this part of our *Introduction to Social Macrodynamics.*

2. BIOLOGICAL

2.1. Birth rate – a woman cannot bear more than once a year;
time scale ~ 1 year;
condition: BIRTH RATE IS EXTREMELY HIGH.

This is a very strong limitation with a short time scale, so it will be the only rule of growth if for any possible reasons the respective condition (birth rate is extremely high) is observed.

2.2. Pubescence – a woman cannot produce children until she is mature;
time scale ~ 15–20 years;
conditions: EARLY CHILD-BEARING.

This condition is less strong than 2.1., but in fact condition 2.1. is rarely observed. For real demographic processes limitation 2.2. is more important than 2.1. because in most pre-modern societies women started giving birth very soon after puberty.

3. SOCIAL

3.1. Infant mortality – mortality obviously decreases population growth;
time scale ~ 1–5 years;
condition: LOW HEALTH PROTECTION.

Short time scale; strong and actual limitation for pre-modern societies.

3.2. Mobility – in preagrarian nomadic societies woman cannot have many children, because this reduces mobility;
time scale: ~3 years;
condition: NOMADIC HUNTER-GATHERER WAY OF LIFE.

3.3. Education – education increases the "cost" of individuals; it requires many years of education making high procreation undesirable. High human cost allows an educated person to stand on his own economically, even in old age, without the help of offspring. These limitations reduce the birth rate;
time scale: ~25–40 years;
condition: HIGHLY DEVELOPED EDUCATION SUBSYSTEM.

All these limitations are objective. But each of them is ACTUAL (that is it must be included in equations) ONLY IF RESPECTIVE CONDITIONS ARE OBSERVED.

If for any considered historical period several limitations are actual (under their conditions) then, neglecting the others, equations for this period must involve their implementation.

According to the Tikhonov theorem, the strongest factors are the ones having the shortest time scale. HOWEVER, factors with a longer time scale may "start working" under less severe requirements, making short-time-scale factors not actual, but POTENTIAL.

Let us observe and analyze the following epochs:

I. pre-agrarian societies;
II. agrarian societies;
III. post-agrarian societies.

We shall use the following notation:

– atypical – means that the properties of the epoch make the conditions practically impossible;

– actual – means that such conditions are observed, so this limitation is actual and must be involved in implementation;

– potential – means that such conditions are not observed, but if some other limitations are removed, this limitation may become actual.

I. Pre-agrarian societies (limitation statuses):
1.1. – ACTUAL[2]
1.2. – ACTUAL[3]
2.1. – potential
2.2. – ACTUAL
3.1. – ACTUAL
3.2. – ACTUAL
3.3. – atypical

II. Agrarian societies (limitation statuses):
1.1. – ACTUAL
1.2. – ACTUAL
2.1. – potential
2.2. – ACTUAL
3.1. – ACTUAL
3.2. – atypical
3.3. – potential

III. Post-agrarian societies (limitation statuses):
1.1. – atypical
1.2. – potential/ACTUAL[4]
2.1. – potential
2.2. – potential
3.1. – atypical
3.2. – atypical
3.3. – ACTUAL

With our macromodels we only described agrarian and post-agrarian societies (due to the lack of some necessary data for pre-agrarian societies). According to the Tikhonov theorem, to describe the DYNAMICS of the system we should take the actual factor which has the LONGEST time-scale (it will represent dynamics, while shorter scale factors will be involved as coefficients – solutions of algebraic equations).

So epoch [II] is characterized by 1.2, and [III] by 3.3. ([III] also involves 1.2, but for [III] resource limitation 1.2 is much less essential, because it con-

[2] Systematic (not occasional short-term) starvation is caused by imbalance of technology and population, so 1.1. may be included in 1.2.
[3] According to the Tikhonov theorem, we may neglect the oscillations of population (demographic cycles), because their time scales are at least 10 times shorter than the scale of the historical period which is taken into account.
[4] Technology produces much more than is necessary for sustenance, but the growing living standards also require more resources.

cerns growing life standards, and not vitally important needs). Thus, the demographic transition is a process of transition from II:[1.2] to III:[3.3].

Limitation 3.3 at [III] makes biological limitations unessential but potential (possibly, in the future, limitation 3.3 could be reduced, for example, through the reduction of education time due to the introduction of advanced educational technologies, thereby making [2.2] actual again; possibly cloning might make [2.1] and [2.2] obsolete, so there would become apparent new limitations).

In conclusion, we want to note that hyperbolic growth is a feature which corresponds to II:[1.2]; there is no contradiction between hyperbolic growth itself and [2.1] or [2.2]. Hyperbolic agrarian growth never does reach the birth-rate, which is close to conditions of [2.1]. If it was so, hyperbola will obviously convert into an exponent, when birth-rate comes close to [2.1] (just as physical velocity may never exceed the velocity of light) – and it would not be a weakness of the model, just common sense. It would be just [1.2] → [2.1, 2.2].

But actual demographic transition [1.2] → [3.3] is more drastic than this [1.2] → [2.1, 2.2]! [3.3] is reducing the birth-rate much more actively, and it may seem strange: the system WAS MUCH CLOSER TO [2.1] and [2.2] WHEN IT WAS GROWING SLOWER – during the epoch of [II]! (This is not nonsense, because slower growth was the reason of [2.1] and [3.1]).

As for the "after-doomsday dynamics", if there is no resource or spatial limitation (as well as [3.1]), then [2.1] and [2.2] will become actual. If they are also removed (through cloning, *etc.*), then there will appear new limitations.

But if we consider the solution of $C/(t_0 - t)$ just formally, the after-doomsday dynamics make no sense. But this is "normal", just as temperature below absolute zero, or velocity above the velocity of light, makes no sense.

Thus, as we have seen, 99.3–99.78 per cent of all the variation in demographic, economic and cultural macrodynamics of the world over the last two millennia can be accounted for by very simple general models.

Actually, this could be regarded as a striking illustration of the fact well known in complexity studies – that chaotic dynamics at the microlevel can generate highly deterministic macrolevel behavior (*e.g.*, Chernavskij 2004).

To describe the behavior of a few dozen gas molecules in a closed vessel we need very complex mathematical models, which will still be unable to predict the long-run dynamics of such a system due to an inevitable irreducible chaotic component. However, the behavior of zillions of gas molecules can be described with extremely simple sets of equations, which are capable of predicting almost perfectly the macrodynamics of all the basic parameters (and just because of chaotic behavior at the microlevel).

Our analysis suggests that a similar set of regularities is observed in the human world too. To predict the demographic behavior of a concrete family we would need extremely complex mathematical models, which would still predict a very small fraction of actual variation due simply to inevitable irreducible chaotic components. For systems including orders of magnitude higher numbers of people (cities, states, civilizations), we would need simpler mathematical models having much higher predictive capacity. Against this background it is hardly surprising to find that the simplest regularities accounting for extremely large proportions of all the macrovariation can be found precisely for the largest possible social system – the human world.

This, of course, suggests a novel approach to the formation of a general theory of social macroevolution. The approach prevalent in social evolutionism is based on the assumption that evolutionary regularities of simple systems are significantly simpler than the ones characteristic of complex systems. A rather logical outcome of this almost self-evident assumption is that one should first study the evolutionary regularities of simple systems and only after understanding them move to more complex ones.[5] We believe this misguided approach helped lead to an almost total disenchantment with the evolutionary approach in the social sciences as a whole.[6]

In the first part our *Introduction to Social Macrodynamics* we tried to consider the simple macroregularities of the long-term World System growth. In this part we have tried to analyze more complex regularities of its dynamics on shorter scales, as well as dynamics of its constituent parts paying special attention to cyclical dynamics on a "secular" scale.

We have found that the structure of millennial trends cannot be adequately understood without secular cycles being taken into consideration. At a certain level of analysis millennial trends turn out to be a virtual byproduct of the political-demographic cycle mechanisms, which turn out to incorporate certain trend-creating mechanisms. Demographic-political cycle models can serve as a basis for the development and testing of models accounting not only for secular cycles but also for millennial trends. In order to do this, we suggest to alter the basic assumptions of the earlier generations of political-demographic cycle models (first of all, that subsistence technology and carrying capacity of land are constant). These are variables with long-term trend dynamics in the rise of carrying capacity of land and sociocultural complexity that the new generation of models needs to account for, which could provide a more accurate description of secular cyclical dynamics as well. We shall try to demonstrate this in the next part of our *Introduction to Social Macrodynamics*.

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[5] A major exception here is constituted by the world-system approach (*e.g.*, Braudel 1973; Wallerstein 1974, 1987, 2004; Frank 1990, 1993; Frank and Gills 1994; Chase-Dunn and Hall 1997; Denemark *et al.* 2000; Chase-Dunn *et al.* 2003; Modelski 2003; Devezas and Modelski 2003; Chase-Dunn and Anderson 2005, *etc.*), but the research of world-system theorists has up to now yielded rather limited results, to a significant extent, because they avoided the use of standard scientific methods and mostly remained on the level of verbal constructions (with a notable exception of Devezas and Modelski [2003]).

[6] In fact, a similar fate would have stricken physicists if a few centuries ago they had decided that there is no real thing such as gas, that gas is a mental construction, and that one should start with such a "simple" thing as a mathematical model of a few free-floating molecules in a closed vessel.

<u>Appendix 1</u>

An Empirical Test of the Kuznets – Kremer Hypothesis

In 1993 Michael Kremer proposed the following equation for the description of the relationship between technological growth rate and population:

$$\frac{dT}{dt} = bNT \ , \tag{0.8}$$

where T is technology, N is population, and b is average innovating productivity per person.

This hypothesis[1] can be formulated verbally in the following way: the absolute growth rate of technology at moment t is proportional, on the one hand, to technological level achieved by this moment,[2] and on the other hand, to population size observed at this moment (that is, to the number of potential inventors).

This equation has already been used in a rather extensive way for the mathematical modeling of historical macroprocesses (Cohen 1995; Komlos and Nefedov 2002; Tsirel 2004; Podlazov 2000, 2001, 2002, 2004;[3] Korotayev, Malkov, and Khaltourina 2006 *etc.*), though, as far as we know, this hypothesis has never been tested empirically, which makes the necessity to perform such a test especially pressing.

To perform such a test we used the World System Technological Development Index, which we calculated on the basis of Hellemans – Bunch database (1988). In this database Hellemans and Bunch tried to record all the main inventions and discoveries that had been made by the 1980s. We defined the index's value for year t as the total number of important inventions and discoveries made within the World System by this year.

The overall dynamics of the World System Technological Development Index look as follows (see Diagram A1.1):

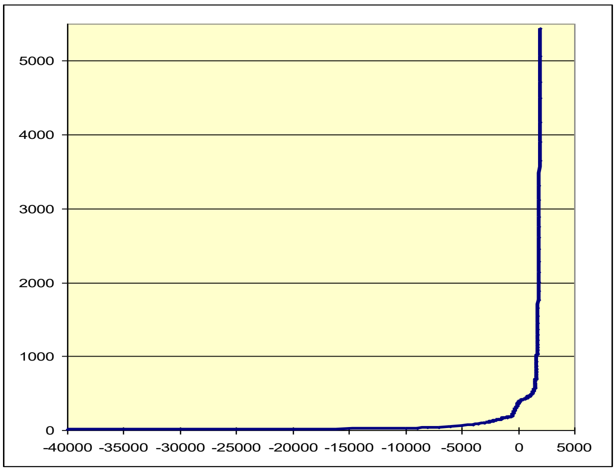
---

[1] As the basic idea underlying Kremer's equation was (to our knowledge) first expressed by Simon Kuznets (1960), we shall denote the respective hypothesis as the Kuznets – Kremer one.

[2] The wider is the technological base, the more possibilities for new technological innovations/inventions it provides.

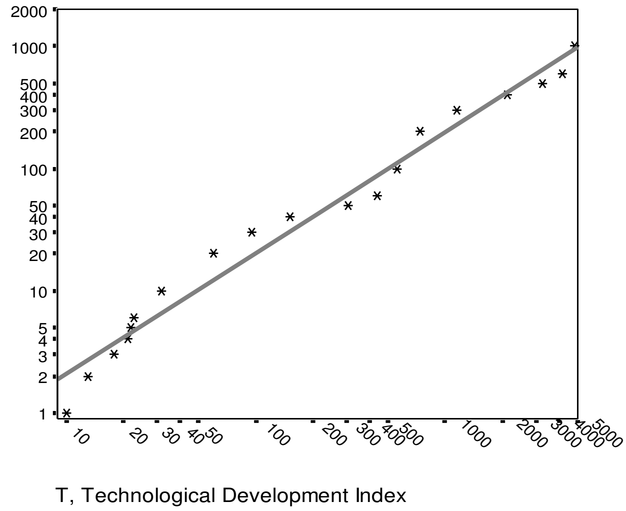
[3] It appears necessary to mention that Andrey Podlazov and Sergei Tsirel arrived at this equation quite independently from Kremer.

Diagram A1.1. Technological Development Index Dynamics (40000 BCE – 1970 CE)



Note that this index shows a very strong correlation with the calibrated version of the Technological Development Index calculated by Leonid Grinin (2006) using a very different methodology (see Diagram A1.2):

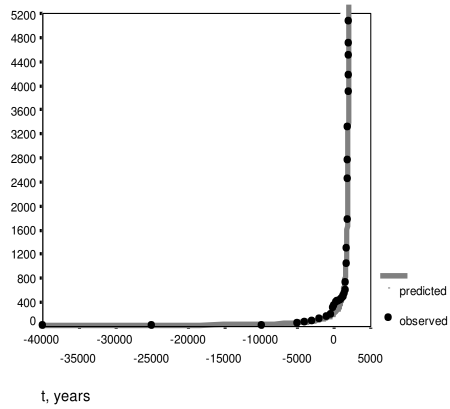
Diagram A1.2. Correlation between the Technological Development Index (*T*) and Calibrated Grinin Index (I_c) (40000 BCE – 1955 CE): scatterplot with a fitted regression line



NOTE: $R = 0.978$, $R^2 = 0.956$, $p = 4.6 \times 10^{-13}$.

Quite predictably the Technological Development Index demonstrates a pronounced long-term hyperbolic dynamics (see Diagram A1.3):

Diagram A1.3. Technological Development Index Dynamics, 40000 BCE – 1960 CE: correlation between predictions of simple hyperbolic model and observed data



NOTES: R = 0.996, R^2 = 0.992, p << 0.0001. Black markers correspond to our empirical estimates based on the Hellemans – Bunch database (1988). The solid grey curve has been generated by the following equation:

$$T_t = \frac{464803{,}8}{(2047 - t)}.$$

Parameters C (341303.3) and t_0 (2047) have been determined with the least squares method. For comparison the best-fit exponential model gives here R^2 = 0.785. The value of t_0 appears to be overestimated due to the underestimation of the number of important inventions made after 1870 by the Hellemans – Bunch database.[4]

If the Kuznets – Kremer Hypothesis is true, then the average number of inventions and discoveries made per year during period A should be proportional to the product of the number of inventions made before this period[5] and the population size (that is the number of potential inventors) observed by the beginning of this period.

---

[4] Indeed, there are sufficient grounds to suppose that, from the mid 19th century on, Bunch and Hellemans tend to undercount more and more the inventions and discoveries made in each respective year. Thus, they definitely underestimate the growth of technological innovation activity in the second half of the 19th century, when, for example, in the USA 23140 inventions registered in the 1850s were succeeded by c. 440,000 inventions registered in the three subsequent decades, and the overall "rate of technological innovation grew 7 times between 1860 and 1890" (Grinin 2003: 145); yet Hellemans and Bunch (1989: 318–72) register for this period just a twofold increase, which therefore appears to be an underregistration, even taking into consideration the fact that this growth in the USA exceeded the one in almost all the other countries of the world. This underregistration appears to be accounted for mainly by technical reasons. The fact is that by the mid 19th century Hellemans and Bunch confronted such a level of innovation activity that even a short description of all the important inventions and discoveries made in a respective year started to occupy more than 2 large-format pages, so that from this time on they had to omit more and more important inventions and discoveries simply to avoid the excessive growth of their volume (which still runs to 700 large-format pages).

[5] That is, Technological Development Index at the beginning of period A.

Our analysis of the Hellemans – Bunch database has produced the following results (see Table A1.1 and Diagram A1.4):

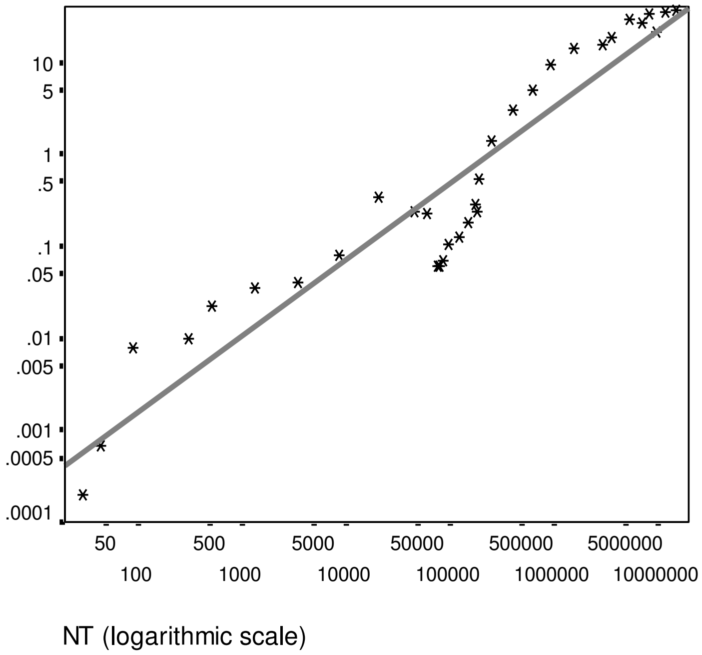
Table A1.1. Long-Term Demographic-Technological Dynamics

i (years)	T_i (technological development index = number of important inventions and discoveries made by year *i*)	*N* (world population, mlns. in year *i*)	*NT*	*dT* (number of inventions and discoveries made during the period beginning in year *i*)	*dT*/*dt* (average number of inventions and discoveries made per year during the period beginning in year *i*)
-40000	10	3	30	3	0.0002
-25000	13	3.34	43.42	10	0.000667
-10000	23	4	92	40	0.008
-5000	63	5	315	10	0.01
-4000	73	7	511	22	0.022
-3000	95	14	1330	35	0.035
-2000	130	27	3510	41	0.041
-1000	171	50	8550	39	0.078
-500	210	100	21000	100	0.333333
-200	310	150	46500	47	0.235
0	357	170	60690	48	0.228571
210	405	190	76950	12	0.06
410	417	190	79230	12	0.06
610	429	200	85800	14	0.07
810	443	220	97460	21	0.105
1010	464	265	122960	11	0.122222
1100	475	320	152000	18	0.18
1200	493	360	177480	28	0.28
1300	521	360	187560	24	0.24
1400	545	350	190750	53	0.53
1500	598	425	254150	141	1.41
1600	739	545	402755	305	3.05
1700	1044	610	636840	249	4.98
1750	1293	720	930960	476	9.52
1800	1769	900	1592100	690	13.8
1850	2459	1200	2950800	302	15.1
1870	2761	1300	3589300	556	18.53333
1900	3317	1625	5390125	583	29.15

i (years)	T_i (technological development index = number of important inventions and discoveries made by year *i*)	*N* (world population, mlns. in year *i*)	*NT*	*dT* (number of inventions and discoveries made during the period beginning in year *i*)	*dT*/*dt* (average number of inventions and discoveries made per year during the period beginning in year *i*)
1920	3900	1813	7070700	271	27.1
1930	4171	1987	8287777	330	33
1940	4501	2213	9960713	212	21.2
1950	4713	2555.36	12043412	355	35.5
1960	5068	3039.67	15405048	370	37
1970	5438	3708.07	20164485		

NOTE: world population data are from Kremer 1993.

Diagram A1.4. Correlation between *NT* and Absolute Technological Growth Rate (*dT/dt*): scatterplot in double logarithmic scale with fitted regression line, 40000 BCE – 1970 CE



NOTE: $R = + 0.934$, $R^2 = 0.872$, $p = 2.9 \times 10^{-16}$

As we see, our empirical test has provided unequivocal support for the Kuznets – Kremer Hypothesis: the correlation has turned out to be in the predicted direction, very strong and significant beyond any doubt. It suggests that variation of *NT* accounts for more than 87% of the macrovariation of absolute technological growth.

Appendix 2

Compact Mathematical Models of the World System Development and Macroperiodization of the World System History

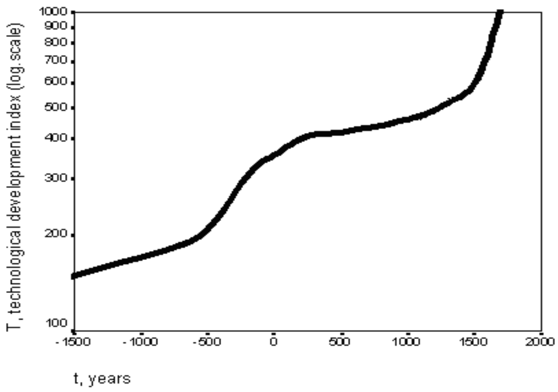
Compact mathematical models of the World System development (surveyed in the Introduction) suggest the following macroperiodization of its history:

1. the era of hyperbolic growth, blow-up regime development (= "Malthusian-Kuznetsian" era), up to the 1960s – 1970s;
2. the era of the divergence from the blow-up regime (= "post-Malthusian" era).

Within this context the 1960s – 1970s could be regarded as a transitional period between the two eras.

On the other hand, the blow-up regime development era can be subdivided into two relatively independent epochs of hyperbolic growth (the Older Hyperbola and the Younger Hyperbola), the border between which appears to be marked by the end of the Axial Age (for the notion of the Axial Age see, *e.g.*, Jaspers 1953; Eisenstadt 1982, 1986; Gellner 1988).

Diagram A2.1. Technological Development Index Dynamics (1500 BC – 1700 CE), logarithmic scale

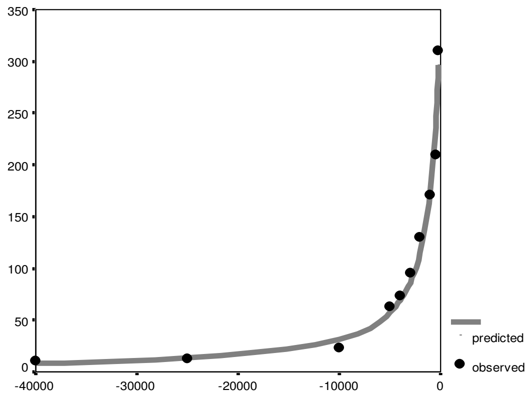


Note that the second ("Younger") hyperbola entirely overwhelms the first. Thus, at Diagram A1.1 above the Axial Age looks like merely a small "bump" that disrupts, in a slightly annoying way, the elegant form of the almost perfect technological growth hyperbola. To see that the Big Hyperbola consists of two smaller ones we have to "zoom in" at the Axial Age part of the Diagram (see Diagram A2.1).

Let us recollect, that in logarithmic scale a hyperbolic curve looks like an exponential one, which lets us see in a rather distinct way that the large hyperbola actually consists of two smaller ones, with the exit from the first hyperbola being accompanied by entering the second.

Yet, are there sufficient grounds to consider the overall World System technological dynamics before the end of the Axial Age as generally hyperbolic? The mathematical analysis suggests that the hyperbolic model describes these dynamics in a rather accurate way (see Diagram A2.2):

Diagram A2.2. Technological Development Index Dynamics, 40000 BCE – 200 CE: correlation between predictions of simple hyperbolic model and observed data



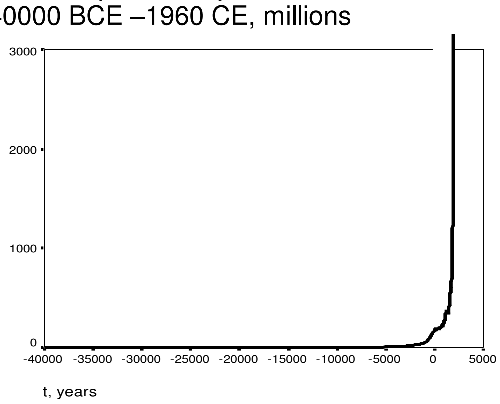
NOTES: $R = 0.993$, $R^2 = 0.986$, $p << 0.0001$. Black markers correspond to our estimates made on the basis of the Hellemans – Bunch (1988) database. The solid grey curve has been generated by the following equation:

$$T_t = \frac{341303.1}{(950 - t)}.$$

Parameters C (341303.3) and t_0 (950) have been calculated with the least squares method. For a comparison, the best-fit exponential model gives here a significantly worse fit with the empirical estimates ($R^2 = 0.785$).

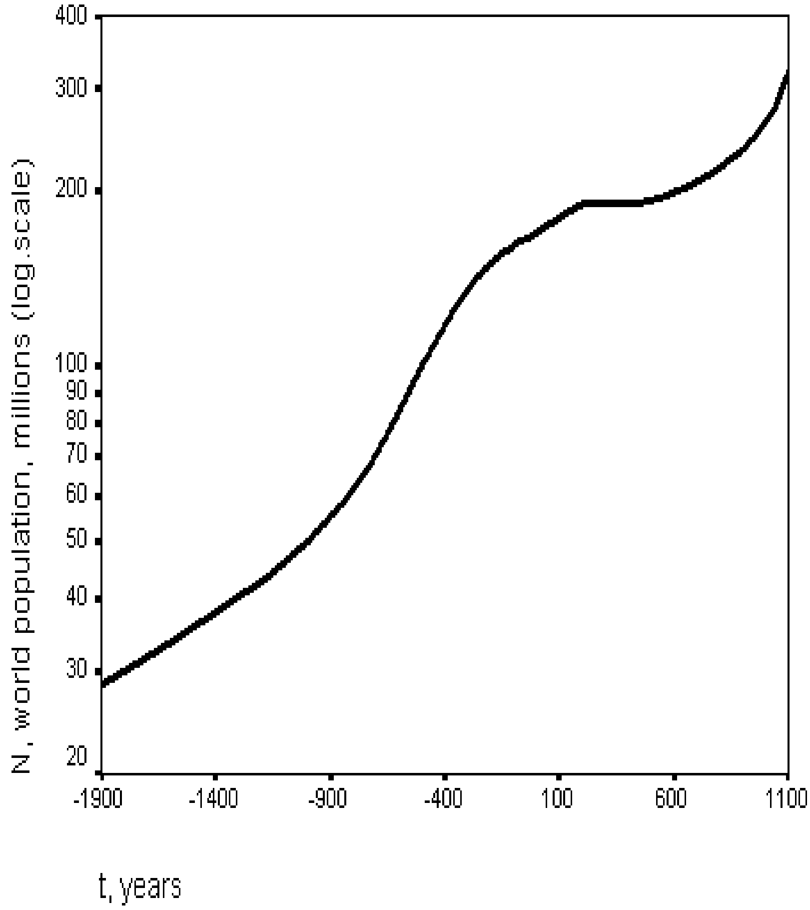
It is by no means easier to see that the macrocurve of the World System hyperbolic growth consists of two hyperbolas when we inspect an overall diagram of the world population growth (see Diagram A2.3):

Diagram A2.3. World Population Dynamics, 40000 BCE –1960 CE, millions



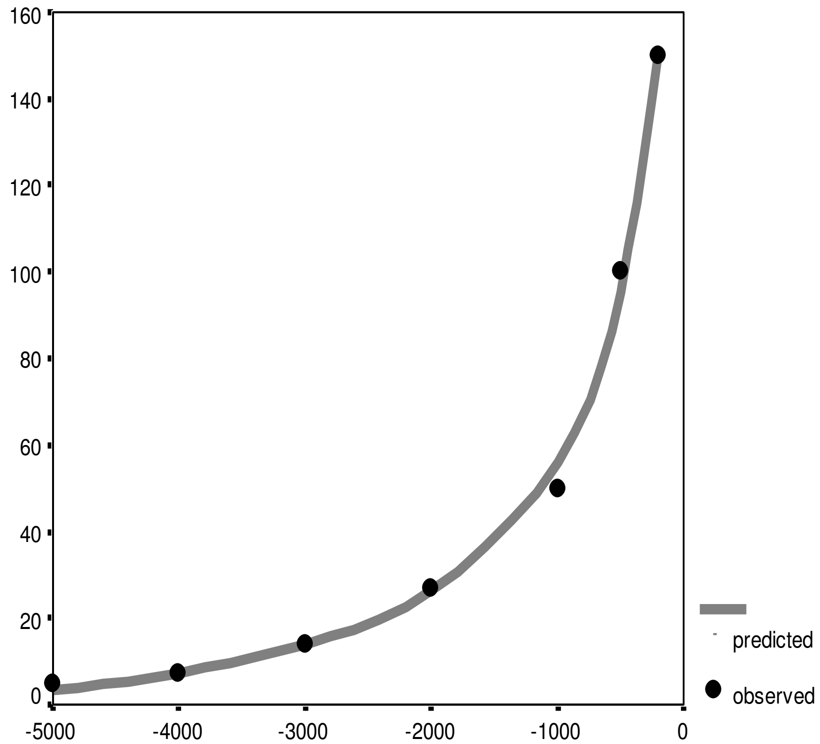
However, in this case too the "zooming in" at the "Axial Age bump" in logarithmic scale detects two adjacent hyperbolic curves such that exit from the first is accompanied by entering the second (see Diagram A2.4):

Diagram A2.4. World Population Dynamics (1900 BCE – 1100 CE), millions, logarithmic scale



The mathematical analysis confirms the overall hyperbolic pattern of the World System demographic dynamics until the end of the Axial Age (see Diagram A2.5):

Diagram A2.5. World Population Dynamics (in millions), 5000 – 500 BCE: correlation between predictions of simple hyperbolic model and empirical estimates



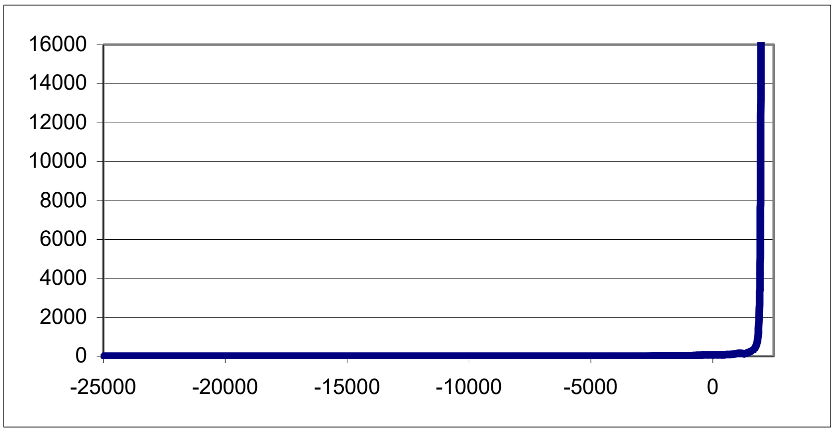
NOTES: R = 0.998, R^2 = 0.996, p << 0.0001. Black markers correspond to Kremer's estimates (1993). The grey solid curve has been generated by the following equation:

$$N_t = \frac{99674.642}{(400-t)} - 15.29 \cdot$$

Parameters C (99674.642), t_0 (400) and constant (– 15,29) have been calculated with the least squares method. For the period 40000 – 200 BCE the correlation with the best-fit hyperbolic model is a bit weaker (R^2 = 0.990 with t_0 = 275). For comparison, the best-fit exponential model here gives R^2 = 0.459 for the period 40000 – 200 BCE and R^2 = 0.973 for the period 5000 – 200 BCE.

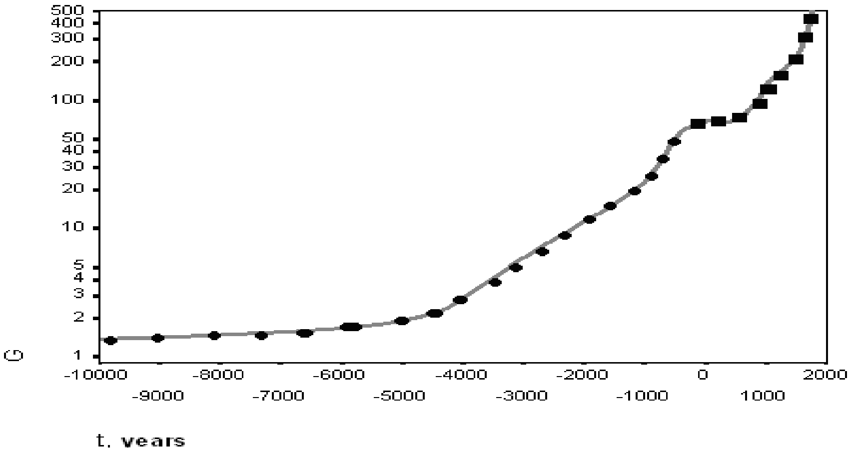
As the world GDP up to 1973 grew in a quadratic-hyperbolic (rather than simple hyperbolic) way, it appears simply impossible to see two hyperbolas in a diagram of its growth made on the basis of DeLong's (1999) estimates, inasmuch as the Younger Hyperbola totally overshadows the Older one (see Diagram A2.6):

Diagram A2.6. World GDP Growth, 25000 BCE – 1973 CE, billions of international 1990 dollars, PPP



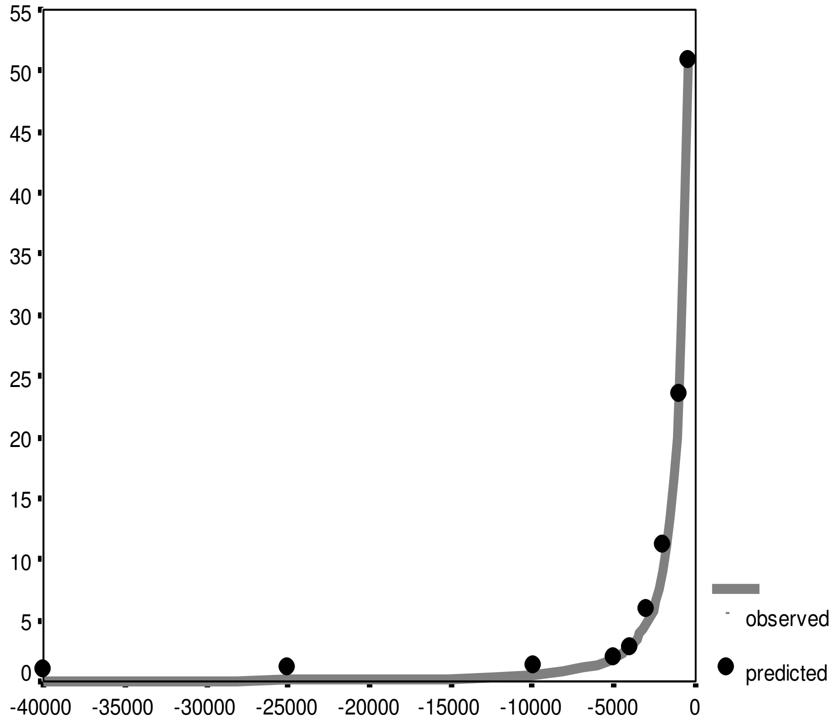
However, even here an inspection of the diagram in logarithmic scale clearly reveals the presence of two adjacent heterometric hyperbolas flowing into each other around the end of the Axial Age (see Diagram A2.7):

Diagram A2.7. World GDP (*G*) Growth from 10000 BCE to the second half of the 18th century, in billions of international 1990 dollars, PPP, logarithmic scale



Mathematical analysis of DeLong's estimates indicates that the overall economic dynamics of the World System until the end of the Axial Age was quadratic-hyperbolic (see Diagram A2.8):

Diagram A2.8. World GDP Dynamics (in billions of international 1990 dollars, PPP), 40000 – 500 BCE: correlation between predictions of quadratic-hyperbolic model and DeLong's estimates



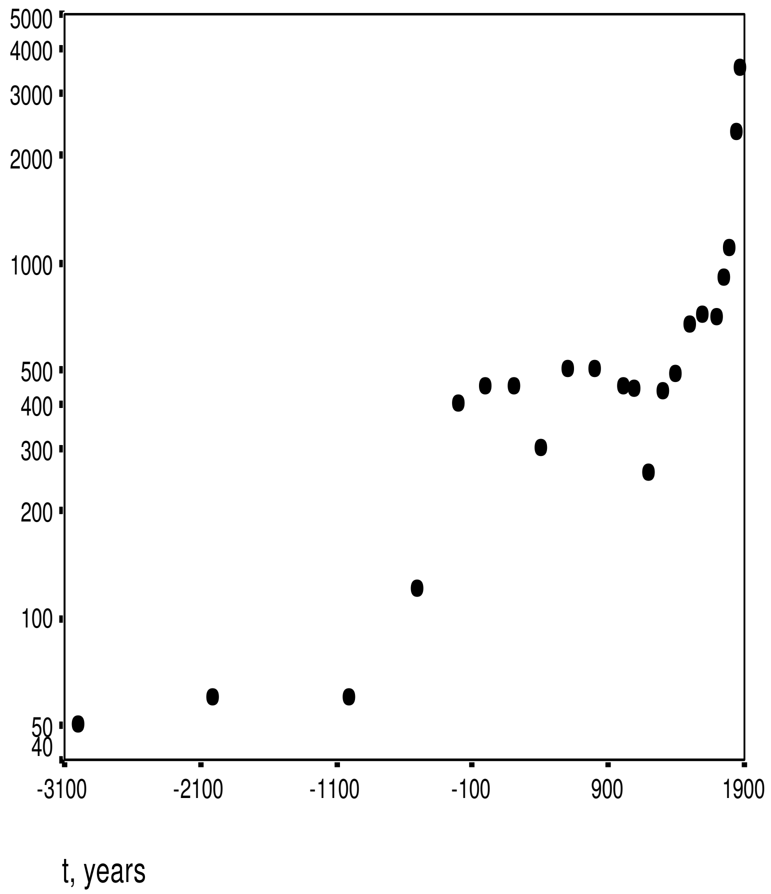
NOTES: R = 0.999, R^2 = 0.998, p << 0.0001. Black markers correspond to DeLong's (1999) estimates. The solid grey curve has been generated by the following equation:

$$G_t = \frac{61303619.77}{(595 - t)^2}.$$

Parameters C (61303619.77) and t_0 (595) have been calculated with the least squares method. For the period 40000 – 200 BCE the correlation with the quadratic-hyperbolic model is a bit weaker (R^2 = 0.986 with t_0 = 1200). For comparison, the best-fit exponential model here gives R^2 = 0.420 for the period 40000 – 200 BCE and R^2 = 0.475 for the period 40000 – 500 BCE.

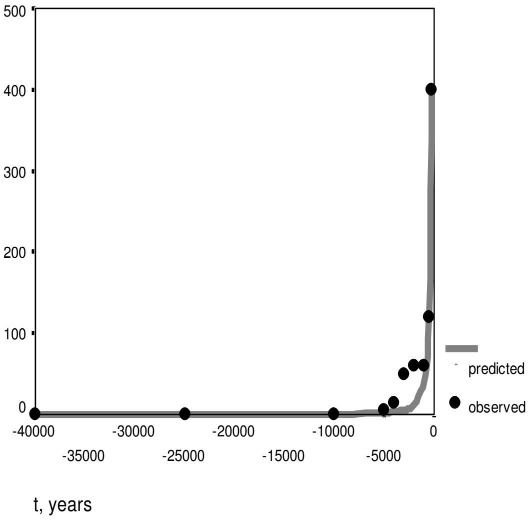
Two hyperbolic curves can also be traced in the dynamics of so important an indicator as the population of the largest city of the World System (see Diagram A2.9):

Diagram A2.9. Dynamics of Population of the Largest Settlement of the World System, in thousands, 3000 BCE – 1870 CE, logarithmic scale



The mathematical analysis confirms that the overall dynamics of the largest World System settlement population were quadratic-hyperbolic up to the end of the Axial Age (see Diagram A2.10):

Diagram A2.10. Dynamics of Population of the Largest Settlement of the World System, in thousands, 40000 – 200 BCE: correlation between predictions of quadratic-hyperbolic model and empirical estimates



NOTES: $R = 0.989$, $R^2 = 0.978$, $p << 0{,}0001$. Black markers correspond to the estimates of Modelski (2003) and Chandler (1987). The solid grey curve has been generated by the following equation:

$$U_{\max t} = \frac{56637733.865}{(175-t)^2}$$

Parameters C (56637733.865) and t_0 (175) have been calculated with the least squares method. For comparison, the best-fit exponential model here gives $R^2 = 0.805$.[1]

Taking into consideration what was mentioned in the Introduction, this suggests that the overall dynamics of the growth of general sociocultural complexity of the World System also followed a quadratic-hyperbolic pattern up to the end of the Axial Age. Note that for the "Younger Hyperbola" epoch we observe very strong correlations between the population of the largest city of the World System and such variables as its urbanization/percentage of urban population ($R = 0.99$; $p < 0.001$), overall urban population ($R = 0.98$; $p < 0.001$), world literacy ($R = 0{,}98$; $\alpha < 0{,}001$), and overall literate population ($R = 0.99$; $p < 0.001$).[2] If the proportions between the main indicators of the World System

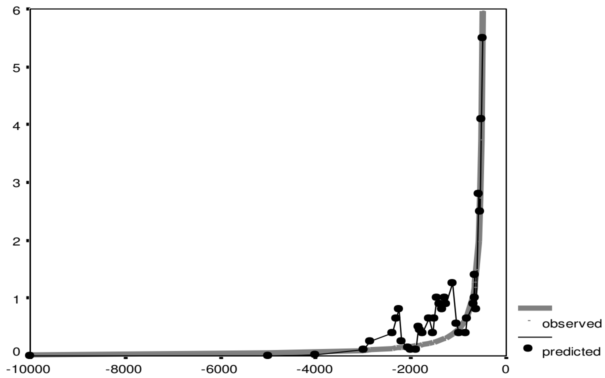
[1] Note that this diagram suggests the question whether the "Older Hyperbola" does not consist itself of two hyperbolic curves. At the moment we do not have sufficient empirical data to answer this question.

[2] Calculated on the basis of data sources described in notes to diagrams of this appendix and the Introduction.

development are basically the same within the Older Hyperbola as they are within the Younger Hyperbola, the quadratic-hyperbolic growth of the largest World System settlement population could be regarded as an indirect indicator of the fact that up to the end of the Axial Age the World System development was characterized by hyperbolic trends of urbanization and literacy growth, as well as by quadratic-hyperbolic trends of the growth of urban and literate population.[3]

An interesting mathematical model developed by Robert Graber (1995) suggests that in the long run the hyperbolic growth of population in a limited area should be accompanied by the hyperbolic growth of an average territorial size of this zone's polities. Against this background it is hardly surprising to find that the hyperbolic growth of the World System population up to the end of the Axial Age was accompanied by the hyperbolic growth of the largest World System polity, especially pronounced before 500 BCE (see Diagram A1.11):

Diagram A2.11. The Size of the Largest Polity of the World System Dynamics (in millions km^2), 10000 – 500 BCE: correlation between predictions of hyperbolic model and Taagapera's estimates



NOTES: R = 0.952, R^2 = 0.906, p << 0.0001. Black markers correspond to Taagapera's (1968, 1978a, 1978b, 1979, 1997) estimates. The solid grey curve has been generated by the following equation:

$$P_t = \frac{250.462}{(-458 - t)}.$$

Parameters C (250.462) and t_0 (– 458) has been calculated with the least squares method. For comparison, the best-fit exponential model here gives R^2 = 0.858. Note that for the period 10000 –

[3] Of course, this statement needs an independent empirical test that appears impossible at the moment due to the lack of respective empirical quantitative data. Note that we cannot use here even the data (which we used above in the Introduction) on dynamics of urban population living in cities with > 250,000 inhabitants, as such cities only appeared specifically in the Axial Age.

176 BCE the correlation with the hyperbolic model is substantially weaker (R^2 = 0.906 with t_0 = 15), and is not significantly different from a best-fit exponential model.

It appears relevant to pay attention to which dates we find as critical time (t_0) for the "Older Hyperbolas" (see notes to Diagrams A2.2, 5, 8, and 10). These dates are as follows: 950 CE for technology, 400 CE for population, 595 CE for GDP, 175 CE for the population of the largest city, and 15 CE for the largest polity size. In other words, if the hyperbolic trends of the World System development observed up to the end of the Axial Age had continued further just for a few centuries, already in the 1st millennium CE all the main indicators of the World System development would have become infinite. It is very clear that such a scenario was impossible by definition. Thus, in any case the hyperbolic regime of the World System growth observed up to the end of the Axial Age could not continue further for any significant period of time, and was bound to change within a few centuries (as its continuation would have involved such absolutely impossible things as, *e.g.*, the growth of the largest city up to 57 billion[4] by 174 CE and its departure to infinity the following year). And, indeed, after the end of the Axial Age the World System diverges from the blow-up regime. The hyperbolic World System dynamics change to logistic for a significant period of time, which resembles the present-day macroepoch. But this resemblance is very superfluous indeed.

As was mentioned in the Introduction, in the present epoch the divergence from the blow-up regime takes place against the background of a rapidly rising standard of living for most inhabitants of the world and is caused by this very growth, which, for example, allows educational level to rise to such an extent that it causes fertility decline (and thus the transition of the World System population growth pattern from hyperbolic to logistic), on the one hand; and on the other hand, it brings world literacy ever more rapidly to the saturation level (and with the same result – the transition from hyperbolic to logistic dynamics).

During "the First Transitional Epoch", divergence from the blow-up regime took place in just the opposite way – through the decline (frequently down to negative values) of economic growth rates and, consequently, declining living standards for most of the World System population; rising mortality; and decline (frequently down to negative values) of the rates of literacy and urbanization growth, notwithstanding the fact that both of them were very far from the saturation level.

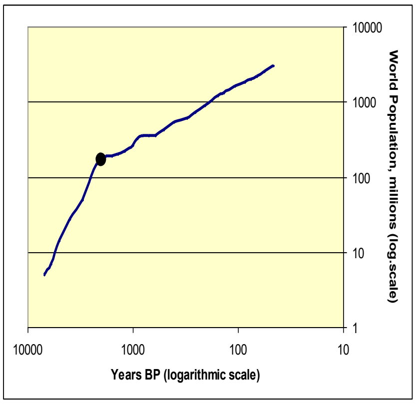
As has been already mentioned, the divergence from the "Older Hyperbola" was at the same time tantamount to entering the new, "Younger Hyperbola". It is important to stress that this process was by no means a mere return to the old hyperbolic trajectory; rather, it was a radical change of hyperbolic growth regimes that accompanied the radical transformation of the World System itself. It may be said in a somewhat metaphoric way that the World System could not stand the fast acceleration of the hyperbolic growth regime that it experienced for a few thousand years after the start of the Agrarian Revolution; and after the Axial Age it moved to a new regime of a smoother, but more stable hyperbolic acceleration.

[4] See equation in the note to Diagram A1.10.

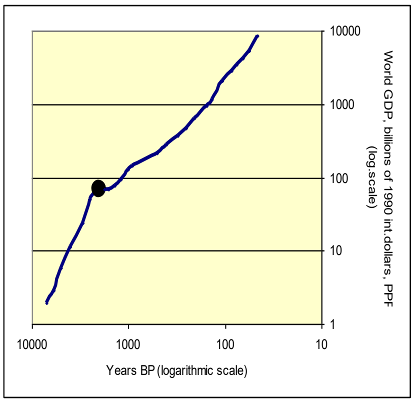
This can be seen rather clearly if we inspect the dynamics of the four indices of World System development for which we have very long-term estimates at our disposal (except the largest polity size[5]), in double logarithmic scale (see Diagram A2.12–15):

Diagrams A2.12–15. Long-Term Dynamics of the Main Indicators of the World System Development, double logarithmic scale

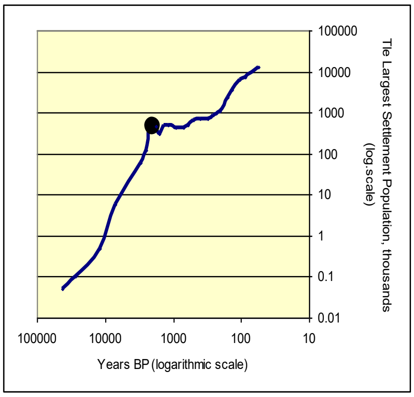
A2.12. World population (till 1960)



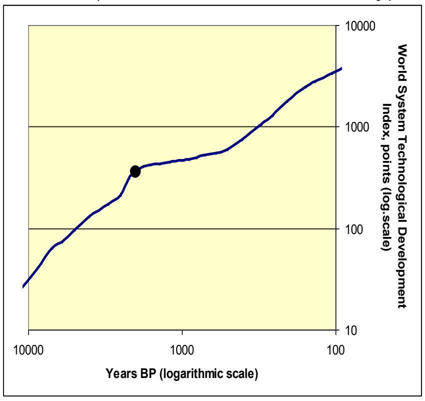
A2.13. World GDP (till 1960)



A2.14. The largest settlement population (until 1950)



A2.15 Technological development index (until the late 19th century)



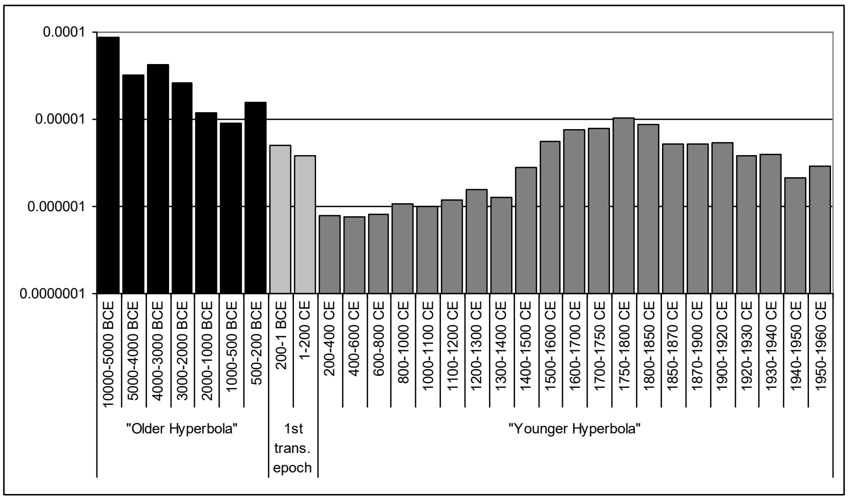
NOTE: the black round marker denotes data point corresponding too 200 BCE, that is, roughly the end of the Axial Age.

[5] In the post-Axial era, the hyperbolic growth trend for largest polity size within the World System seems to disappear (see Taagapera 1968, 1978a, 1978b, 1979, 1997), which testifies additionally for a qualitative difference between the Older and Younger Hyperbolas.

Let us recollect that in double logarithmic scale a hyperbola looks like a straight line, with a steeper slope of this line corresponding to a higher rate of hyperbolic acceleration. Thus, the dynamics of all four of the indicators for which we have very long-term quantitative empirical estimates suggest the same picture: transition from a regime of relatively more rapid hyperbolic acceleration that was typical for the World System's development before the end of the Axial Age to a regime of slower (but apparently more stable) "post-Axial" hyperbolic acceleration. Thus, the "Big Hyperbola" of the World System's development breaks up into two "Small Hyperbolas" – the "Older" and "Younger" ones – that differ from each other in their basic characteristics.

The fact that we are dealing here with two different regimes of hyperbolic growth could be seen, for example, through the comparison of values of coefficient *b* (from Kremer's technological growth equation [0.8]), which is interpreted by Kremer himself as "research productivity per person" (Kremer 1993: 686) (see Diagram A2.16):

Diagram A2.16. Dynamics of Per Capita Invention Productivity Coefficient (logarithmic scale)



NOTE: calculated on the basis of Table A1.1.

As has been already noted above, the values of this coefficient seem to be underestimated for the post-1850 period; however, even taking this point into consideration, the radical difference between the "Older" and "Younger" hyperbolas is rather evident.[6]

[6] Of course, the supposition that per capita invention productivity of the Modern World System could be substantially lower than the one of the Neolithic or Chalcolithic World System may look totally implausible, as modern technological growth rate is so evidently and radically faster than

A detailed consideration of the concrete causes and mechanisms of the World System's divergence from the blow-up regime in the post-Axial period, a significant slow-down of the speed of World System development, and the change of hyperbolic growth regimes lies beyond the scope of this monograph. Here we shall restrict ourselves to an attempt to trace just a few possible ways to address this question (note that they are not mutually exclusive):

1) The growth of the World System population by the end of the 1st millennium BCE up to 9-digit numbers produced a breeding ground that led to an almost inevitable appearance of a new generation of more lethal and epidemically destructive pathogens that could not reproduce themselves in smaller populations (Diamond 1999: 202–5; Korotayev, Malkov, and Khaltourina 2005: 105–13), whereas the level of health care technologies achieved by the World System by the beginning of the 1st millennium CE turned out to be totally inadequate for the radically increased level of pathogen threat. Thus, the Antonine and Justinian's pandemics led to global depopulations of the 2nd and 6th centuries, contributing in a very significant way to the slow down of the World System demographic growth in the 1st millennium CE. Note that due to this, since the early 1st millennium CE the role of health care technologies as a determinant of the carrying capacity of the Earth dramatically increases, which at least partly accounts for the change of the hyperbolic growth regime.

2) Some hint here seems to be suggested by mathematical models (0.11)-(0.13)-(0.12) and (0.13)-(0.14) described in the Introduction. According to these models any long-term decrease of per capita surplus (*S*) must lead to the decrease of population growth rates and, hence, the slow-down of technological growth. In the meantime, by the end of the Axial Age we seem to observe a World System trend towards the decline of precisely this indicator. This was connected not with decline of production, but rather with the growth of *m*, the per capita product that is necessary for the population reproduction with zero growth rate, the "minimum necessary product" (MNP). In the 1st millennium BCE the rapid population growth sustained the hyperbolic growth of the complexity of sociopolitical infrastructures (on the other hand, of course, the hyper-

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it was in the Neolithic. However, it appears necessary to take into consideration the fact that modern technological progress is being achieved with an orders-of-magnitude higher number of potential inventors, and on an orders-of-magnitude wider technological base. In the meantime, an orders-of-magnitude smaller population of the pre-Axial World System that had at its disposal an orders-of-magnitude less developed technology managed to make an immense number of the most fundamental inventions and technological innovations that formed the backbone of the modern technology – suffice to mention the domestication of wheat, barley, cattle, sheep and goats, development of technologies of ceramic and textile production, copper, bronze, and later iron metallurgy and metal work, invention of wheel, plow, writing, money, credit, taxation, formal education and so on. It appears difficult to provide a simple answer to the question on possible causes of the sharp decrease of per capita invention productivity after the Axial Age. Could it not have some connection with the Axial Age transition from pre-Axial "sympractical" (Romanov 1991) thinking to the transcendentally oriented one (Eisenstadt 1982)? Note that, though this transition involved a minority of population, this was just the most creative minority.

bolic population growth was also sustained by a hyperbolic growth of sociopolitical complexity – once more we are dealing here with the positive feedback phenomenon). However, the radical increase in sociopolitical complexity meant a radical increase in the MNP, as the substantial expenses necessary for the normal functioning of these sociopolitical infrastructures should be regarded, in this context, as a part of the minimum necessary product (rather than as surplus). Indeed, by the end of the 1st millennium BCE the World System population reached 9-digit numbers; simply reproducing (at zero growth rate) so huge a population required maintenance of normal functioning of all those infrastructures (transportation, judicial, administrative and other such subsystems). Within such a context, if the product produced this year by a peasant is only sufficient to secure the survival of himself and his household, but not sufficient to pay any taxes, it is impossible to say that this peasant has produced this year the minimum necessary product. In fact, what he has produced this year is smaller than the MNP. Indeed, as the experience of post-Axial centuries showed on numerous occasions, in supercomplex agrarian societies the decrease of per capita production (usually as a result of relative overpopulation) down to a level that does not allow the population to pay taxes led to the disintegration of sociopolitical infrastructures and demographic collapse (see Chapters 1–4 above). There are grounds to maintain that the rapid growth of the MNP in the 1st millennium BC exceeded the growth of the equilibrium per capita production, which resulted in the long-term decrease of real *S*, and, hence, the decrease of the World System population growth rates. On the other hand, it led to the decrease of sociopolitical system stability, and, hence, to the increase in the importance of the role of cyclical and chaotic components of the macrohistorical dynamics in comparison with the trend component. Note, however, that this point can account only for the decrease of the speed of technological growth acceleration; it cannot explain the decrease in the absolute rates of technological growth apparently observed in the 1st millennium CE.

3) The point that the change of the hyperbolic growth regime took place after the political centralization of the World System had reached, at hyperbolical speed, a critical level (by the end of the 1st century CE the absolute majority of the World System inhabitants found themselves under the control of just four polities – the Roman, Parthian, Kushana, and Han empires) does not appear coincidental, in light of some additional considerations. The precipitous growth of the World System political centralization observed in the 1st millennium BCE (Taagapera 1968, 1978a, 1978b, 1979, 1997) was propelled, among other things, by the diffusion and development of iron metallurgy, which not only raised substantially the carrying capacity of the Earth but also led to the development of mass production of relatively cheap but effective weapons; and these allowed the formation of mass armies, which were in their turn a necessary condition for empire formation. However, those processes had important side effects. Politically centralized systems frequently achieve military superiority

through the development of specialized military subsystems with relatively small but well trained and armed professional armies. However, a necessary condition of the continuation of such superiority is normally the monopoly over certain effective weapons (chariots, bronze arms *etc.*). If a certain revolution in the production of the means of violence leads to the appearance of some effective weapons the monopoly over which could not be effectively maintained (*e.g.* iron arms), less politically-centralized societies with a higher military participation ratio then acquire considerable advantages, and could become militarily stronger than more politically centralized ones (which appears to have taken place in many parts of the Old World Oikumene in the early Iron Age, or the Late Antiquity). In addition to that, less politically-centralized societies with a high military participation ratio could increase significantly their military efficiency, without any considerable increase in their political centralization or internal differentiation (*e.g.* through nomadization), by increasing specialization in animal husbandry, inasmuch as the routine economic activity and socialization of a herder tends to produce a warrior (see, *e.g.*, Irons 2004). The full-scale nomadic economy (employing extensive use of the mounts) would increase the military potential of such societies in an especially significant way without any corresponding significant increase in the degree of their political centralization and functional differentiation. What seems important in this context is that the technological developments of the 1st millennium BCE eventually led to the military strengthening of the barbarian periphery in general and of the nomadic systems in particular. It seems possible to argue that for many centuries afterwards (that is, for most of the Younger Hyperbola epoch), the World System experienced a phase of its technological development during which the nomads had a systematic military advantage over sedentary systems (an advantage enhanced by the invention and rapid diffusion of stirrups and sabers) that contributed in the most significant way to the slow-down of the World System's population growth in the post-Axial millennium. Note that this is to a very considerable extent accounted for precisely by a series of barbarian invasions, which produced depopulations in all the parts of the world system. Note that, *e.g.*, Western European population managed to grow over the 2nd century CE level only after the end of barbarian invasions (see, *e.g.*, McEvedy and Jones 1978). Indeed, during this period the pressure of the barbarian peripheries in general (and nomadic ones in particular) seems to have been, along with epidemics, an extremely important factor checking the World System's population growth. What was important was not just that the barbarian invasions led to significant depopulations (like the 13th century Mongolian invasions); what was perhaps more important yet is that the pressure of the barbarian (and especially nomadic) peripheries systematically lowered the carrying capacity of land in many parts of the World System. For example, the "Black Soil" area of Southern Russia and Ukraine (which since the 19th century produced most marketable food within the Russian Empire/USSR) was known for most of the 2nd millennium

CE as the "Wild Field" because, for most of this millennium, most of the land in this area remained uncultivated due precisely to the nomadic threat (see, *e.g.*, Turchin 2005b).

Thus, the analysis of the World System's history against the background of mathematical models of its development confirms the fundamental correctness of Karl Jaspers' (1953) suggestion to consider the Axial Age (the expressive notion of which was introduced just by Jaspers) as a sort of central milestone that divides the World System history into two comparable parts.

Note that the available periodizations of the World System's history (*e.g.*, Shofman 1984; Gellner 1988; Diakonov 1994; Goudsblom 1996; Green 1992, 1995; McNeill 1995; Rozov 2001) have failed to capture the complex character of the hyperbola of the World System's development, the precipitous acceleration by the end of the Axial Age, a radical slow-down during the subsequent period, the change of regimes of hyperbolic growth, and, finally, the current divergence from the blow-up regime. Karl Jaspers' work suggests possible approaches to the development of more adequate periodizations, which still remains a task for the future.

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