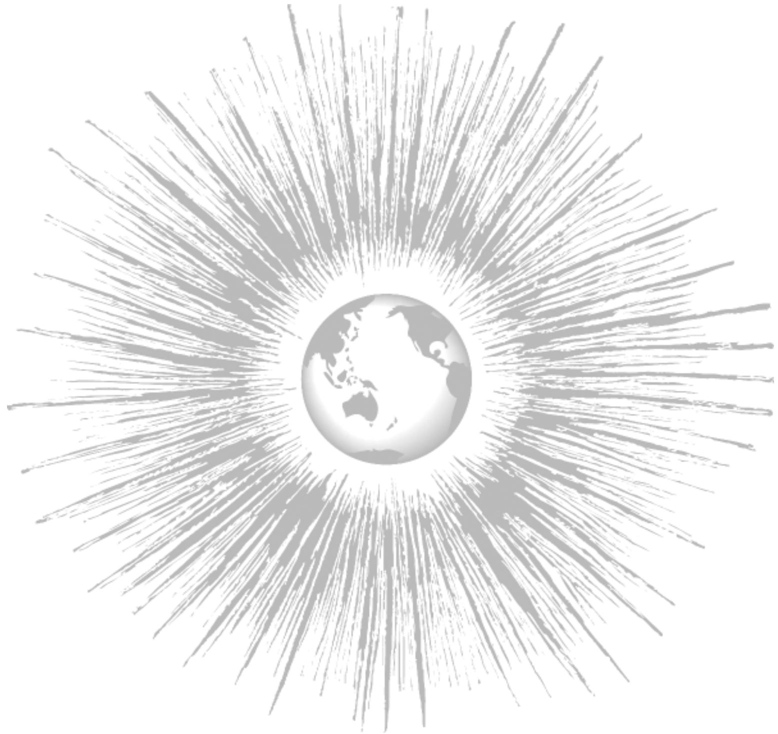


ABSTRACT:

The fact that up to the 1960s world population growth had been characterized by a hyperbolic trend was discovered quite some time ago. A number of mathematical models describing this trend have already been proposed. Some of these models are rather compact but do not account for the mechanisms of this trend; others account for this trend in a very convincing way, but are rather complex. In fact, the general shape of world population growth dynamics could be accounted for with strikingly simple models like the one which we would like to propose ourselves: *dN/dt = a (bK – N) N* (1); *dK/dt = cNK* (2), where *N* is the world population, *K* is the level of technology/knowledge, *bK* corresponds to the number of people (*N*), which the earth can support with the given level of technology (*K*). Empirical tests performed by us suggest that the proposed set of two differential equations account for 96.2–99.78% of all the variation in demographic macrodynamics of the world in the last 12,000 years. We believe that the patterns observed in pre-modern world population growth are not coincidental at all. In fact, they reflect population dynamics of quite a real entity, the world system. Note that the presence of a more or less well integrated world system comprising most of the world population is a necessary pre-condition, without which the correlation between the world population numbers generated by hyperbolic growth models and the observed ones would not be especially high. In fact, our findings could be regarded as a striking illustration of the fact well known in complexity studies—that chaotic dynamics at the microlevel can generate a highly deterministic macrolevel behavior. Against this background it is hardly surprising to find that the simplest regularities accounting for extremely high proportions of all the macrovariation can be found just for the largest possible social system—the world system.

A Compact Macromodel of World System Evolution

Andrey Korotayev

The fact that up to the 1960s[1] world population growth had been characterized by a hyperbolic[2] trend was discovered quite some time ago (see, e.g., von Foerster, Mora, and Amiot 1960; von Hoerner 1975; Kremer 1993; Kapitza 1992, 1999). A number of mathematical models describing this trend have already been proposed (see, besides the above references, Cohen 1995; Johansen and Sornette 2001; Tsirel 2004; Podlazov 2004). Some of these models (e.g. von Foerster, Mora, and Amiot 1960; or Kapitza 1992) are rather compact but do not account for the mechanisms of this trend; some others (first of all Kremer 1993) account for this trend in a very convincing way, but are rather complex. In fact, the general shape of world population growth dynamics could be accounted for with strikingly simple models like the one which we would like to propose ourselves below (or the one proposed by Tsirel [2004]).

With Kremer (1993), Komlos and Nefedov (2002), and others (Habakkuk 1953; Postan 1950, 1972; Braudel 1973; Abel 1974, 1980; Cameron 1989; Artzrouni and Komlos 1985), we make "the Malthusian (1978) assumption that popula-

Andrey Korotayev
Program in "Anthropology of the East"
Russian State University for the Humanities
6 Miusskaya Ploshchad
Moscow 125267, Russia
korotayev@yahoo.com

1. Actually, up to 1962/63. After 1962–63, as a result of the world demographic transition the actual world population dynamics began to diverge more and more from the hyperbolic curve, and by the present moment world population growth rates have declined dramatically as compared with 1963. It appears possible to develop a mathematical model describing both pre-1962 hyperbolic growth and the subsequent global demographic transition; however, this would go out of the scope of the present article.

2. Hyperbolic population growth implies that absolute population growth is proportional to the square of population (unlike exponential growth in which absolute

JOURNAL OF WORLD-SYSTEMS RESEARCH, XI, I, JULY 2005, 79–93
http://jwsr.ucr.edu/
ISSN 1076–156X

tion 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),[3] and that, on the other hand, "high population spurs technological change because it increases the number of potential inventors…[4] In a larger population there will be proportionally more people lucky or smart enough to come up with new ideas"[5] (Kremer 1993: 685), thus, "the growth rate of technology is proportional to total population"[6] (Kremer 1993: 682; see also, e.g., Kuznets 1960; Grossman and Helpman 1991; Aghion and Howitt 1992, 1998; Simon 1977, 1981, 2000; Komlos and Nefedov 2002).

The simplest way to model mathematically the relationships between these two subsystems (which, given the current state of our knowledge, has not been proposed yet) is to use the following set of differential equations:

growth is lineally proportional to population). Thus, with exponential growth, if at the world population level of 100 million the absolute annual growth was 100,000 people a year, at the 1 billion level it will be 1 million people each year (the tenfold growth of population leads to the same tenfold increase in the absolute population growth rate). With hyperbolic growth, if at the world population level of 100 million the absolute annual growth was 100,000 people a year, at the 1 billion level it will be 10 million people a year (the tenfold growth of population leads to the 100-fold increase in the absolute population growth rate). Note that the relative population growth rate will remain constant with exponential growth (.1% in our example), whereas it will be lineally proportional to the absolute population level with hyperbolic growth (in our example, population growth by a factor of 10 leads to the tenfold increase in the relative annual growth rate, from .1% to 1%).

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

4. "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).

5. The second assumption is in fact Boserupian rather than Malthusian (Boserup 1965; Lee 1986).

6. Note that "the growth rate of technology" means here relative growth rate (that is to which level the technology will grow in the given unit of time in proportion to the level observed at the beginning of this period). This, of course, implies that the absolute speed of technological growth in the given period of time will be proportional not only to the population size, but also to the absolute level of technology at the beginning of this period.

$$dN/dt = a\,(bK - N)\,N \quad (1)$$

$$dK/dt = cNK \quad (2)$$

Where N is the world population, K is the level of technology/knowledge, bK corresponds to the number of people (N), which the earth can support with the given level of technology (K).

With such a compact model we are able to reproduce rather well the long-run hyperbolic growth of world population before 1962–3.

With our two-equation model we start our first simulation in the year 1650 and do annual iterations with difference equations derived from the differential ones:

$$K_{i+1} = K_i + cN_iK_i$$
$$N_{i+1} = N_i + a(bK_{i+1} - N_i)N_i$$

We choose the following values of the constants and initial conditions: $N = 0.0545$ of tens of billions (i.e. 545 million);[7] $a = 1$; $b = 1$; $K = 0.0545$;[8] $c = .05135$.[9] The outcome of the simulation, presented in Figures 1–2 indicates that irrespective of all its simplicity the model is actually capable of replicating quite reasonably the population estimates of Kremer (1993), the US Bureau of the Census (2004), and other sources (Thomlinson 1975; Durand 1977; McEvedy and Jones 1978: 342–51; Biraben 1980; Haub 1995: 5; UN Population Division 2004; World Bank 2004) in most of their characteristics (see Figure 1)

The correlation between the predicted and observed values for this imitation looks as follows: $R = .9989$, $R^2 = .9978$, $p << .0001$, which, of course, indicates an unusually high fit for such a simple macromodel designed to account for the demographic macrodynamics of the most complex social system (see Figure 2).

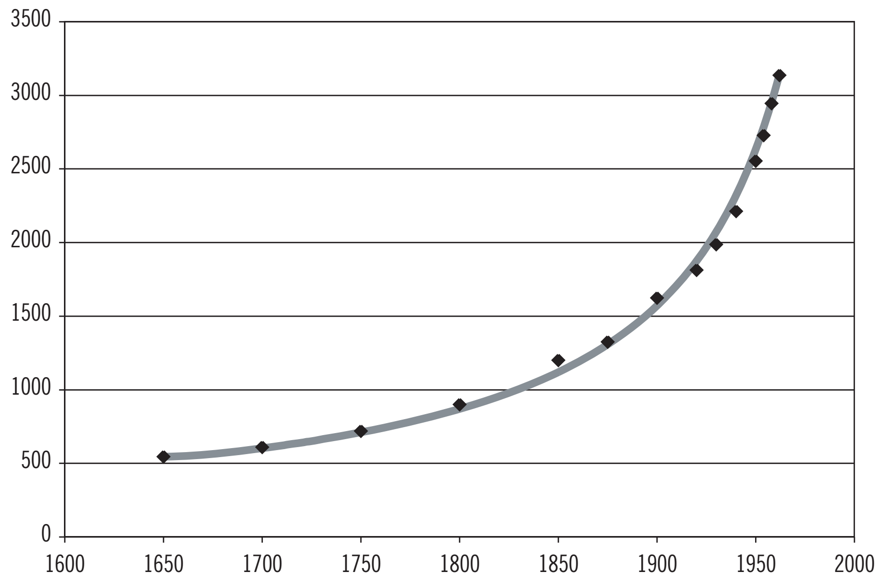
We start our second simulation in the year 500 BCE. In this case we choose the following values of the constants and initial conditions: $N = 0.01$ of tens of

7. We chose to calculate world population in tens of billions (rather than, say, in millions) to minimize the rounding error (which was to be taken most seriously into account in our case, as the object of modeling had evident characteristics of a blow-up regime).

8. To simplify the calculations we chose value "1" for both a and b; thus, K in our simulations was measured directly as the number of people which can be supported by the Earth with the given level of technology (K), and the population was allowed to adjust almost instantaneously to the growth of the Earth's carrying capacity.

9. Given the initial values of N and K, here (as well as in the subsequent simulations) we chose constant c in such a way as to minimize the sum of squared residuals between the observed values and those predicted by our model.

Figure 1 – Predicted and Observed Dynamics of World Population Growth, in Millions (1650–1962 CE)



Note: The solid grey curve has been generated by the model; black markers correspond to the estimates of world population by Kremer (1993) for the pre-1950 period, and US Bureau of Census world population data for 1950–1962.

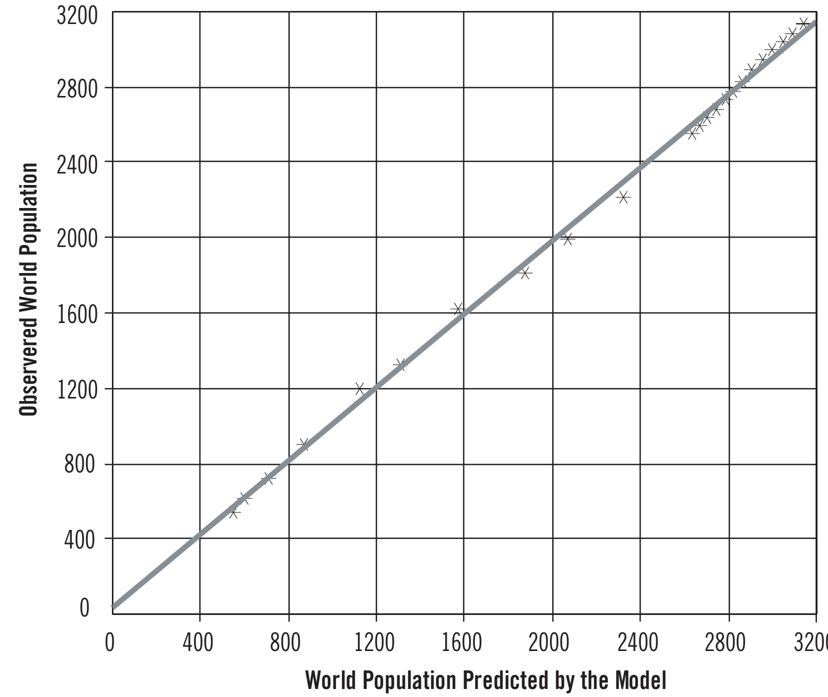
billions (i.e. 100 million); $a = 1$; $b = 1$; $K = 0.01$; $c = 0.04093$. The outcome of the simulation, presented in Figures 3–4 indicates that irrespective of all its simplicity the model is still quite capable of replicating rather reasonably the population estimates of Kremer (1993), US Bureau of the Census (2004) and other sources in most of their characteristics and in terms of the important turning points even for such a long period of time (see Figures 3 and 4).

The correlation between the predicted and observed values for this imitation looks as follows: R = .9983, $R^2 = .9966$, p << .0001, which, of course, again indicates an unusually high fit for such a simple macromodel designed to account for demographic macrodynamics of the most complex social system for *c.* 2500 years (see Figure 4).

Note that even the simulation started *c.* 25000 BCE still produced a fit with observed data as high as .981 ($R^2 = .962$, $p << 0.0001$).[10]

[10] The simulation was started in 24939 BCE and done with 269 centennial iterations ending in 1962 CE. In this case we chose the following values of the constants and initial conditions: $N = 0.00334$ billion (i.e. 3.34 million); $a = 1$; $b = 1$; $K = 0.00334$; $c = 2.13$.

Figure 2 – Correlation Between Predicted and Observed Values (1650–1962)

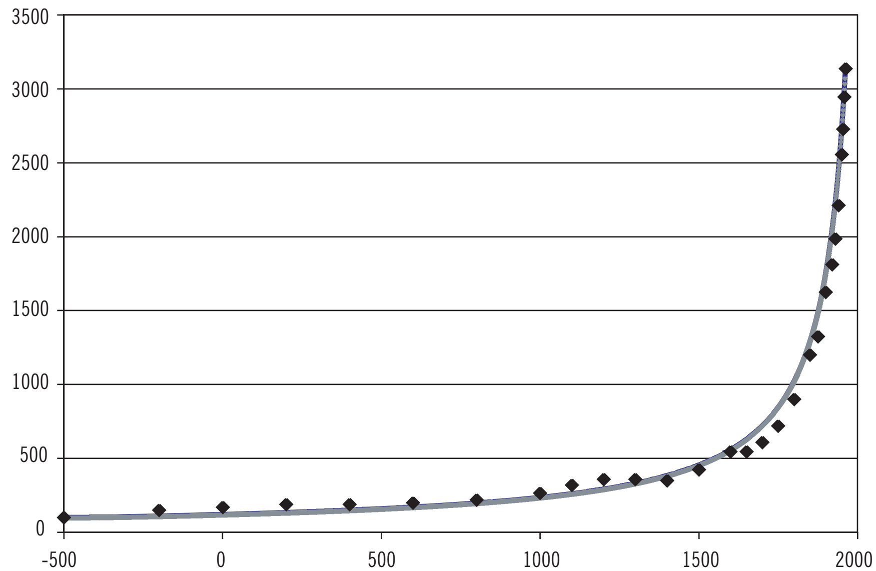


Thus, it turns out that the set of two differential equations specified above accounts for 96.2% of all the variation in the demographic macrodynamics of the world in the last 25 millennia; it also accounts for 99.66% of this macrovariation in 500 BCE–1962 CE, and for 99.78% in 1650–1962 CE.

In fact, we believe this may not be a coincidence that the compact macromodel shows such a high correlation between the predicted and observed data just for 500 BCE–1962 CE. But why does the correlation significantly decline if the pre-500 BCE period is taken into account?

To start with, when we first encountered models of world population growth, we felt a strong suspicion about them. Indeed, such models imply that the world population can be treated as a system. However, at a certain level of analysis one may doubt if this makes any sense whatsoever. For up until recently (especially before 1492) humankind did not constitute any real system, as, for example, the growth of the populations of the Old World, the New World, Australia, Tasmania, or Hawaii took place almost perfectly independently from each other. It seems quite clear, for example, that demographic processes in, say, West Eurasia

Figure 3 – Predicted and Observed Dynamics of World Population Growth, in Millions (500 BCE – 1962 CE)



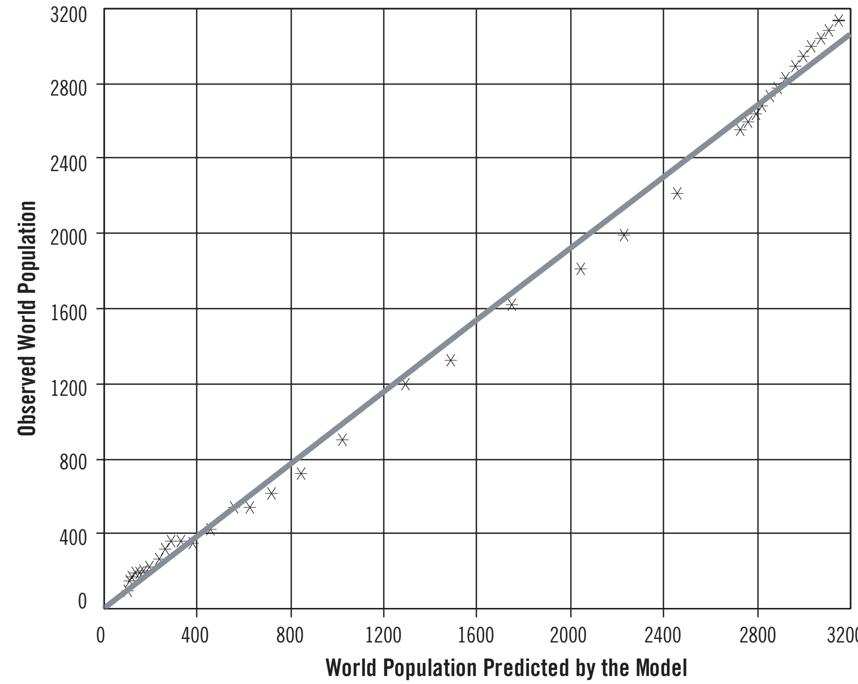
Note: The solid grey curve has been generated by the model; black markers correspond to the estimates of world population by Kremer (1993) for the pre-1950 period, and US Bureau of Census world population data for 1950–1962.

in the first millennium CE did not have the slightest possible impact on the ones in Tasmania in the same time period.

However, we believe that the patterns observed in pre-modern world population growth are not coincidental at all. In fact, they reflect population dynamics of a very real entity, the world system. We are inclined to speak together with Andre Gunder Frank (e.g., Frank and Gills 1994; but not with Wallerstein 1974) about the single world system, which originated long before the "long sixteenth century."

Note that the presence of a more or less well integrated world system comprising most of the world's population is a necessary pre-condition, without which the correlation between world population numbers generated by our model and the observed ones would not be particularly high. For example, suppose we encounter a case where the world population of N grew fourfold but was split into four perfectly isolated regional populations comprising N persons each. Of course, our model predicts that a fourfold increase in world population would tend to lead to a fourfold increase in the relative world technological

Figure 4 – Correlation between Predicted and Observed Values



growth rate. But have we any grounds to expect to find this in the case specified above? Of course not. Yes, even in this case four times the number of people will likely produce four times more innovations. However, the effect predicted by our model would be observed only if innovations produced by any of the four regional populations were shared among all the other populations. However, we assumed that the four respective populations lived in perfect isolation from each other. Hence, as such a sharing would not take place, and the expected increase in the technological growth rate would not be observed, which would produce a huge gap between the predictions generated by our model and the actually observed data.

It seems that it was precisely the first millennium BCE when the world system integration reached a qualitatively new level. A strong symptom of this seems to be the "Iron Revolution," as a result of which iron metallurgy spread within a few centuries (not millennia!) throughout a huge space stretching from the Atlantic to the Pacific, producing (as was already supposed by Jaspers [1953]) a number of important unidirectional transformations in all the main centers of the emerging world system (the Circummediterranean region, the Middle East, South Asia, and East Asia), after which the development of each of these centers cannot be adequately understood, described and modeled without taking into consideration the fact that they were part of a larger and perfectly real whole—the world system.

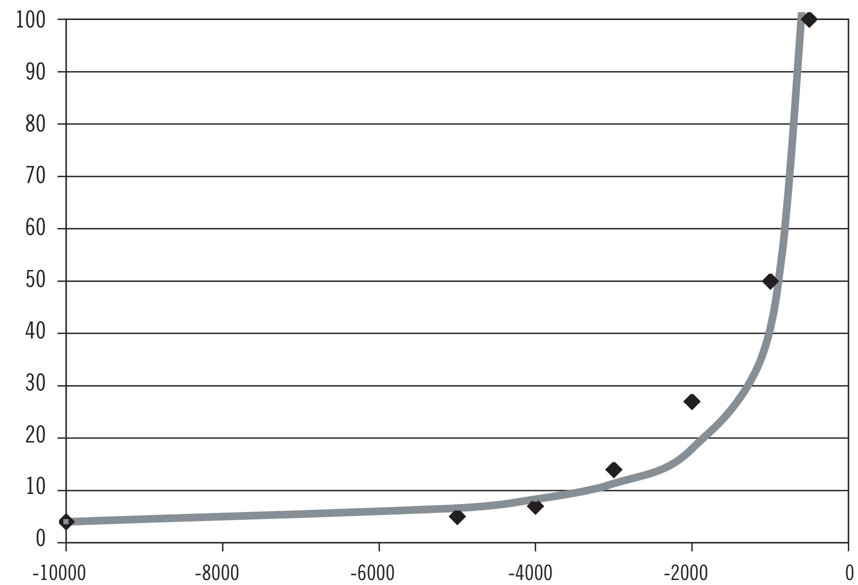
A few other points seem to be relevant here. Of course, there would be no grounds to speak about the world system stretching from the Atlantic to the Pacific even at the beginning of the first Millennium CE if we applied the "bulk-good" criterion suggested by Wallerstein (1974), as there was no movement of bulk goods at all between, say, China and Europe at this time (as we have no grounds not to agree with Wallerstein in his classification of first century Chinese silk reaching Europe as a luxury, rather than a bulk good). However, the first century CE (and even the first millennium BCE) world system would be definitely qualified as such if we were to apply a "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 of the world system is a perfectly sufficient condition, which makes it possible to consider this system as a single evolving entity. In the first millennium BCE no bulk goods could be transported 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 across the whole of Eurasia within a few centuries.

The other point is that even in the first century CE the world system still covered far less than 50% of all the terrain of the Earth. However, what seems to be far more important is that already by the beginning of the first century CE more than 90% of total world population lived just in those regions, which were constituent parts of the first century CE world system (the Circummediterranean region, the Middle East, and South, Central and East Asia) (see, e.g., Durand 1977: 256). Hence, since the first millennium BCE the dynamics of world population reflects very closely the dynamics of the world system population.

On the one hand, it might not be coincidental that the hyperbolic growth trend may still be traced back to 25000 BCE. Of course, I am not going to insist on the existence of anything like the world system, say, around 15000 BP. Note, however, that there does not seem to be any evidence for hyperbolic world population growth in 40000–10000 BCE. In fact the hyperbolic effect within the 25 millennia BCE is produced by the world population dynamics in the last 10 millennia of this period that fits the mathematical model specified above rather well (though not as well as the world population dynamics in 500 BCE–1962 CE [let alone 1650–1962 CE]).

The simulation for 10000–500 BCE was done with the following constants and initial conditions: $N = 0.0004$ of tens of billions (i.e. 4 million); $a = 1$; $b = 1$; $K = 0.0004$; $c = 0.32$.

Figure 5 – Predicted and Observed Dynamics of World Population Growth, in Millions (10000 – 500 BCE)



Note: The solid grey curve has been generated by the model; black markers correspond to the estimates of world population by McEvedy and Jones (1978) and Kremer (1993).

The outcome of the simulation, presented in Figure 5 indicates that the model is still quite capable of replicating rather reasonably the population estimates of McEvedy and Jones (1978) and Kremer (1993) for the 10000–500 BCE period (see Figure 5).

The correlation between the predicted and observed values for this imitation looks as follows: R = .982, R^2 = .964, p = .0001. Note that, though this correlation for 10000–500 BCE remains rather high, it is substantially weaker[11] than the one observed above for the 500 BCE–1962 CE period and, especially, for 1650–1962 CE (in fact this is visible quite clearly even without special statistical analysis in Figures 1, 3, and 5). On the one hand, this result could hardly be regarded as surprising, because it appears evident that in 10000–500 BCE the world system was much less tightly integrated than in 500 BCE–1962 CE (let alone

[11] Note, however, that even for 10000–500 BCE our hyperbolic growth model still demonstrates a much higher fit with the observed data than, for example, the best-fit exponential model ($R^2 = 0.737$, $p = 0.0003$).

in 1650–1962 CE). What seems more remarkable is that for 10000–500 BCE the best fit is achieved with a substantially different value of the coefficient *c*, which appears to indicate that the world system development pattern in the pre-500 BCE epoch was substantially different from the one observed in the 500 BCE–1962 CE era, and thus implies a radical transformation of the world system in the first millennium BCE.

We believe that, among other things, the compact macromodel analysis seems to suggest a rather novel approach to world system analysis. The hyperbolic trend observed for world population growth after 10000 BCE appears to be mostly a product of the growth of the world system, which seems to have originated in West Asia around that time in direct connection with the Neolithic Revolution. The presence of the hyperbolic trend indicates that the major part of the entity in question had some systemic unity, and, we believe we have evidence for this unity. Indeed, we have evidence for the systematic spread of major innovations (domesticated cereals, cattle, sheep, goats, horses, the plow, the wheel, copper, bronze, and later iron technology, and so on) throughout the whole North African–Eurasian Oikumene for a few millennia BCE. As a result, the evolution of societies in this part of the world already at this time cannot be regarded as truly independent. By the end of the first millennium BCE we observe a belt of cultures stretching from the Atlantic to the Pacific with an astonishingly similar level of cultural complexity based on agriculture involving production of wheat and other specific cereals, cattle, sheep, goats, the plow, iron metallurgy, professional armies with rather similar weapons, cavalries, developed bureaucracies, and so on—this list could be extended for pages. A few millennia before we would find a belt of societies with a similarly strikingly close level and character of cultural complexity stretching from the Balkans to the Indus Valley (note that in both cases the respective entities included the major part of the contemporary world population). We would interpret this as a tangible result of the functioning of the world system. The alternative explanations would involve a sort of miraculous scenario—that the cultures with strikingly similar levels and characters of complexity somehow developed independently from each other in a very large but continuous zone, whereas nothing like that appeared in the other parts of the world, which were not parts of the world system. We find such an alternative explanation highly implausible.

It could be suggested that within this new approach the main emphasis should be moved to innovation generation and diffusion. If a society borrows systematically important technological innovations, its evolution already cannot be considered as really independent, but should rather be considered as a part of a larger evolving entity, within which such innovations are systematically produced and diffused. The main idea of a world-systems approach was

to find the evolving unit. The basic idea was that it is impossible to account for the evolution of a single society without taking into consideration that it was a part of a larger whole. However, traditional world-systems analysis concentrated on bulk-good movements, and core–periphery exploitation, thoroughly neglecting the above-mentioned dimension. However, the information network turns out to be the oldest mechanism of world system integration, and remained extremely important throughout its whole history, remaining as important up to the present. It seems to be even more important than core-periphery relations of exploitation (for example, without taking this mechanism into consideration it appears impossible to account for such things as, the demographic explosion in the 20th century, whose proximate cause was the dramatic decline of mortality, but whose main ultimate cause was the diffusion of innovations produced almost exclusively within the world system core). This also suggests a redefinition of the world system (WS) core. The core is not the WS zone, which exploits other zones, but rather the WS core is the zone with the highest innovation donor/recipient (D/R) ratio, the principal innovation donor.[12]

Thus, it turns out that the sets of two differential equations specified above account for 96.2–99.78% of all the variation in demographic macrodynamics of the world in the last 12,000 years. Indeed, our findings could be regarded as a striking illustration of the fact well known in complexity studies—namely, that

12. Earlier we regarded an "information network" as a sufficient condition to consider the entity covered by it as a "world-system." However, some examples seem to be rather telling in this respect. For example, Gudmund Hatt (1949: 104) found evidence on not less than 60 Japanese ships accidentally brought by the Kurosio and North Pacific currents to the New World coast between 1617 and 1876. Against this background it appears remarkable that the "Japanese [mythology] hardly contains any motifs that are not found in America (which was noticed by Levi-Strauss long ago)" (Berezkin 2002: 290–291). Already this fact makes it impossible to exclude entirely the possibility of some information finding its way to the New World from the Old World in the pre-Columbian era, information that could even influence the evolution of some Amerindian mythologies. However, we do not think this is sufficient to consider the New World as a part of the pre-Columbian world system. The Japanese might have even told Amerindians about such wonderful animals as horses, or cows (and some scholars even claim that a few pre-Columbian Amerindian images depict Old World animals [von Heine-Geldern 1964; Kazankov 2005]), the Japanese fishermen might even have had some idea of, say, horse breeding; but all such information would be entirely useless without some specific matter—actual horses. Hence, we would rather denote respective "system-creating" networks as "innovation diffusion networks" rather than just "information networks."

chaotic dynamics at the microlevel can generate a 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 remain incapable of predicting long-run dynamics of such a system due to an inevitably 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).

It appears that a similar set of regularities is observed in the human world too. To predict demographic behavior of a concrete family we would need extremely complex mathematical models, which would still predict a very small fraction of actual variation just due to inevitable irreducible chaotic components. For systems including large 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 high proportions of all the macrovariation can be found just for the largest possible social system—the world system.

This, of course, suggests a novel approach to the formation of the 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 for complex systems. A rather logical outcome from this almost self-evident assumption is that one should study first evolutionary regularities of simple systems and only after understanding them move on to more complex ones.[13] We believe this approach was somehow misleading and led to an almost total disenchantment in the evolutionary approach in the social sciences all together.[14]

---

13. Of course, a major exception here is constituted precisely by a world-systems approach (e.g., Braudel 1973; Wallerstein 1974; Frank and Gills 1994; Chase-Dunn and Hall 1997; Chase-Dunn et al. 2003; among others), but thus far the research of world-systems students has yielded mostly limited results, primarily because they have failed to use to a sufficient extent standard scientific methods implying that verbal constructions should be converted into mathematical models, whose predictions are to be tested with available data.

14. In fact, a similar fate would have stricken physicists if a few centuries ago they decided that there is no real thing like gas, that gas is a mental construction, and one should start with such a simple thing as a mathematical model of a few gas molecules.

REFERENCES

Abel, W. 1974. *Massenarmut und Hungerkrisen im vorindustriellen Europa. Versuch einer Synopsis*. Hamburg: Parey.

Abel, W. 1980. *Agricultural Fluctuations in Europe from the Thirteenth to the Twentieth Centuries*. New York, NY: St. Martin's.

Aghion, P., and P. Howitt. 1992. "A Model of Growth through Creative Destruction." *Econometrica* 60: 323–52.

Aghion, P., and P. Howitt. 1998. *Endogenous Growth Theory*. Cambridge, MA: The MIT Press.

Artzrouni, M., and J. Komlos. 1985. "Population Growth through History and the Escape from the Malthusian Trap: A Homeostatic Simulation Model." *Genus* 41: 21–39.

Berezkin, Yu. E. 2002. "Mythology of American Aborigines: Results of Statistical Analysis of the Motif Spatial Distribution." pp. 277–346 in *History and Semiotics of Amerindian Cultures*, edited by A. A. Borodatova and V. A. Tishkov. Moscow: Nauka. (In Russian.)

Biraben, J. N. 1980. "An Essay Concerning Mankind's Evolution." *Population* 4: 1–13.

Boserup, E. 1965. *The Conditions of Agricultural Growth*. Chicago, IL: Aldine.

Braudel, F. 1973. *Capitalism and Material Life, 1400–1800*. New York, NY: Harper and Row.

Cameron, R. 1989. *A Concise Economic History of the World*. New York, NY: Oxford University Press.

Chase-Dunn, C., A. Alvarez, D. Pasciuti, and A. Jorgenson. 2003. "Time-Mapping Globalization since the Iron Age: Three Thousand Years of Urbanization, Empire Formation and Climate Change." Paper presented at the Annual Meeting of the International Studies Association, Portland, February 27, 2003.

Chase-Dunn, C., and T. Hall. 1997. *Rise and Demise: Comparing World-Systems* Boulder, CO: Westview Press.

Chernavskij, D. S. 2004. *Complexity Studies and Information (A Dynamic Information Theory)*. Moscow: URSS. (In Russian.)

Cohen, J. E. 1995. "Population Growth and Earth's Carrying Capacity." *Science* 269(5222): 341–346.

Durand, J. D. 1977. "Historical Estimates of World Population: An Evaluation." *Population and Development Review* 3(3): 255–96.

Foerster, H. von, P. Mora, and L. Amiot. 1960. "Doomsday: Friday, 13 November, A.D. 2026." *Science* 132:1291–5.

Frank, A. G., and B. Gills, eds. 1994. *The World System: 500 or 5000 Years?* London: Routledge.

Grossman, G., and E. Helpman. 1991. *Innovation and Growth in the Global Economy*. Cambridge, MA: The MIT Press.

Habakkuk, H. J. 1953. "English Population in the Eighteenth Century." *Economic History Review* 6: 117–33.

Hatt, G. 1949. *Asiatic Influences in American Folklore*. København: Ejnar Munksgaard (Det Kgl. Danske Videnskabernes Selskab. Historisk-filologiske meddelelser, 31: 6).

Haub, C. 1995. "How Many People have ever Lived on Earth?" *Population Today* 23(2): 4–5.

Heine-Geldern, R. von. 1964. "Traces of Indian and Southeast Asiatic Hindu-Buddhist Influences in Mesoamerica." *Proceedings of the 35th Int. Congress of Americanists* 1: 47–54.

Hoerner, S. J. von. 1975. "Population Explosion and Interstellar Expansion." *Journal of the British Interplanetary Society* 28: 691–712.

Jaspers, K. 1953. *The Origin and Goal of History*. New Haven, CT: Yale University Press.

Johansen, A., and D. Sornette. 2001. "Finite-time Singularity in the Dynamics of the World Population and Economic Indices." *Physica A* 294(3–4): 465–502.

Kapitza, S. P. 1992. "A Mathematical Model of World Population Growth." *Matematicheskoe Modelirovanie* 4/6: 65–79. (In Russian.)

Kapitza, S. P. 1999. *How Many People did, do and will Live on the Earth? An Essay on the Theory of the Growth of Humankind*. Moscow: Nauka. (In Russian.)

Kazankov, A. A. 2005. *Comparative Mythology and Cultural Diffusion*. Moscow: Institute for African Studies. (In Russian.)

Komlos, J., and S. Nefedov. 2002. "A Compact Macromodel of Pre-Industrial Population Growth." *Historical Methods* 35:92–4.

Kremer, M. 1993. "Population Growth and Technological Change: One Million B.C. to 1990." *The Quarterly Journal of Economics* 108: 681–716.

Kuznets, S. 1960. "Population Change and Aggregate Output." In *Demographic and Economic Change in Developed Countries*. Princeton, NJ: Princeton University Press.

Lee, R. D. 1986. "Malthus and Boserup: A Dynamic Synthesis." pp. 96–130 in *The State of Population Theory: Forward from Malthus*, edited by D. Coleman and R. Schofield. Oxford: Blackwell.

Malthus, T. 1978. *Population: The First Essay*. Ann Arbor, MI: University of Michigan Press.

McEvedy, C. and R. Jones. 1978. *Atlas of World Population History*. New York: Facts on File.

Podlazov, A. V. 2004. "Theory of the Global Demographic Process." pp. 269–72 in *Mathematical Modeling of Social and Economic Dynamics*, edited by M. G. Dmitriev and A. P. Petrov. Moscow: Russian State Social University.

Postan, M. M. 1950. "Some Economic Evidence of Declining Population in the Later Middle Ages." *Economic History Review*. Second series. 2:130–67.

Postan, M. M. 1973. *Essays on Medieval Agriculture and General Problems of the Medieval Economy*. Cambridge: Cambridge University Press.

Simon, J. 1977. *The Economics of Population Growth*. Princeton, NJ: Princeton University Press.

Simon, J. 1981. *The Ultimate Resource*. Princeton, NJ: Princeton University Press.

Simon, J. 2000. *The Great Breakthrough and its Cause*. Ann Arbor, MI: University of Michigan Press.

Thomlinson, R. 1975. *Demographic Problems: Controversy over Population Control*. Second edition. Encino, CA: Dickenson.

Tsirel, S. V. 2004. "On the Possible Reasons for the Hyperexponential Growth of the Earth Population." pp. 367–69 in *Mathematical Modeling of Social and Economic Dynamics*, edited by M. G. Dmitriev and A. P. Petrov. Moscow: Russian State Social University.

U.S. Bureau of the Census. 2004. *World Population Information*. Internet Resource: http://www.census.gov/ipc/www/world.html.

UN Population Division. 2004. *World Population Prospects*. United Nations Department of Economic and Social Affairs, Population Division. Internet Resource: http://www.un.org/esa/population.

Wallerstein, I. 1974. *The Modern World-System 1: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*. New York: Academic Press.

World Bank. 2004. *World Development Indicators*. Washington, DC: World Bank.