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THE ZENO EVENT

Science and the acceleration of history

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It is commonly accepted that the scientific and technological revolution constantly increases its speed. There are a variety of indicators of this process, and an interesting, perhaps important, question is whether they tend to a common conclusion about the future of our society. In this study, we examine several such indicators, relating to both short- and long-term processes. We find that they all agree, predicting a sort of 'Zeno event' around the middle of the next century. This current investigation serves as a signal to those who wish to study the possibility of such a limit-event; its time-series can be tested again in the near future. If they are corroborated, this approach can serve as a well-validated warning, so that we may not merely study the world of the future but also transform it. © 1997 Elsevier Science Ltd

It is usually accepted as a common, well stated 'fact' that the scientific and technological revolution constantly increases its speed. 'Most of scientists are alive', 'the scientific and technological budget increases', 'we live the (second) scientific revolution' are common statements. Most of those claims are qualitative ones, without a long supporting evidence. In this paper we examine a number of time-series, and obtain statistical regularities from them. Their agreement on some limit-event around the middle of the next century is impressive, and this compensates for the uncertainty resulting from the rather speculative quality of much of the data from earlier times.

We have supporting evidence of that phenomenon from studies extending over the last few centuries. 'Adams's law' links the time lag between scientific discovery and industrial application in a mathematical equation. This 'law' predicts a null time lag in the middle of the twenty-first century. In spite of the apparent nonsense of this prediction,

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there is other supporting evidence for the occurrence of a kind of super-event sometime around the middle of the next century. Archaeological evidence also suggests an acceleration of history. The time intervals between humanity's major technological revolutions (stone artifacts, fire, abstract thinking, agricultural societies, slavery, capitalist society) are in a decreasing geometric progression.

This 'law' can be correlated with a similar historic geometric increase in human population. Combining these two empirical laws, we obtain a hyperbolic relation of increasing population against time, with its asymptote (for unbounded growth) again coming in the middle of the next century. Finally, if we construct a simple mathematical model of the penetration of capitalist society into the 'underdeveloped world', we find also a final globalised society appearing around then. These long-term regularities can be taken in conjunction with current well-known facts about the growing instabilities in the environment: increasing pollution, species extinction, greenhouse effect, etc. All these speculations suggest a kind of 'end of technological man'. This would not occur in a mechanical way, with a single 'big bang'; rather, its precursor events would produce changes in social life and social consciousness so that 'quantity would pass into quality' and some new state of being (whose shape we cannot predict here) would emerge.

Adams's 'law'

Henry Adams, in a controversial paper in 1958, presented a quantitative 'law' about the acceleration of technological applications. The equation has been taken even as an artifact, personal bias or joke.[1] Nevertheless the alleged law has an impressive accuracy. Let us consider a choice of relevant technological events, as presented in *Table 1*. If we consider the date of an invention and the date of a common technological application, we can observe, according to Adams, the alleged acceleration.

With such figures, Adams proposes an empirical equation (derived also from Phase Rule Law!) that links discovery date and time-lag between discovery and common technological application:

$$Ae^{-\frac{t}{T}} - B$$

If we select the year 1700 as the time origin, and the parameter values $T = 125$ years, $A = 157$ years, and $B = 9$ years, then we have a good agreement between facts and predicted values, as shown in *Table 1*.

The negative sign in B is the most controversial (and sometimes facetious) point.

TABLE 1. TIME LAG BETWEEN DISCOVERY AND APPLICATION FOR SEVERAL RELEVANT TECHNOLOGICAL EVENTS

Event	Discovery	Application	Difference	Adam's 'law'
Photography	1727	1839	112	117
Steam machine	1769	1854	85	81
Telephone	1820	1876	56	51
Radio	1867	1902	35	32
Radar	1925	1940	15	16
Transistor	1948	1953	5	12
Moon expedition	1961	1969	8	10

Adams's 'law' predicts, in the near future, a zero time lag: every discovery will be instantly applied. Beyond this critical future date, causality reverses (that is the facetious point!). The fatal date is calculated as:

$$t_\infty = T \log \frac{A}{B}$$

The previous parameter values predict a 'technology nightmare' in the year 2057.

It is not a straightforward matter to accept an equation like Adams's. It can be argued that the 'law' is an artifact derived from a biased choice of events. In order to have a more robust data-set, we can use a larger list of technological events, and better still use a list collected by somebody not sympathetic to the 'law'. In *Figure 1*, we present a list of 100 relevant technological events, between 1700 and 1950, selected by a declared opponent of Adams's 'law'[1].

In this case, there is much fluctuation among the data, and there is no mathematically simple function, which provides a good fit. It is not possible to have sharp criteria for parameter adjustment, and there is a large set of parameters that 'adjust to the law'. However, in spite of all these uncertainties, the extrapolated date of the 'technological nightmare' lies around the middle of the next century, perhaps as early as 2040 or as late as 2070. In *Figure 1*, we have selected one set of values, which gives 2062 as the limit date: $T = 207$ years; $A = 132$ years; $B = 23$ years.

Whether or not we wish to believe it, there is no doubt that an effect of acceleration of technological application exits. Adams's equation is just one of the many possible mathematical equations showing that. It is also evident that we have a lot of 'noise'. We cannot expect a precise historical law unless we manage somehow to filter the information.

Archaeological evidence

Acceleration of technology can also be observed in a time interval larger than 250 years. It is simple to construct an archaeological choice of the greatest technological achieve-

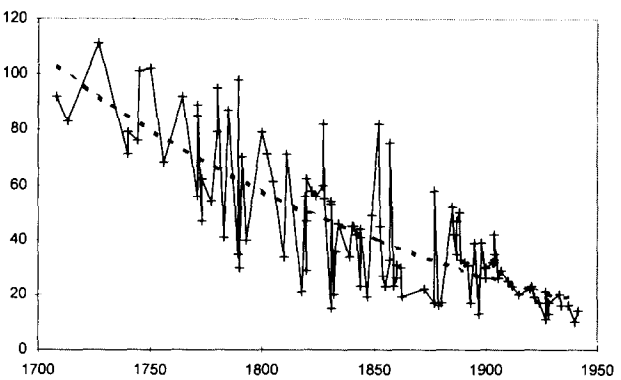

Figure 1. Adams's Law and a hundred technological relevant events. A good adjustment and a lot of noise.

ments in human history. *Table 2* presents (according to the author's preferred choice) a list of the most important events in human history. The table shows also a kind of acceleration (or possibly an artifact!).

The choice of relevant human events intends to select the most important events of all time. Every one is crucial for human civilisation, every one marks an important change in human society. All of them are of similar importance and are associated with a deep social change. The most important event in human history is reaching the erect position. This is the beginning of the use of the hands, instruments, and the beginning of technology. It is previous to every following event in *Table 2*. Stone instruments are a similar milestone. Without stone instruments none of the following events could be possible. Both events happened once, in Africa. The use of fire and the abstract thinking (new social order, private propriety, organised language, cult of the ancestors, possible deadly struggle between Neanderthal and Cro-Magnon men) are the next selected events. The places where those events happened are uncertain. It is possible that they have occurred in several places on the planet.

Agriculture is an obligatory choice; no one can doubt it. It is a well known fact that a new social order was derived from this technological revolution. Irrigation, writing and astronomy are a few technologically related innovations. Agricultural societies are confined, usually, to a fertile valley. Agricultural discovery happened three times, in different places. The 'wheat event' in Mesopotamia and Egypt; the 'rice event' in India, Indochina, China and Japan; the 'corn event' in Central America and Peru. With the name of 'slavery' we designate a new social order with several technological innovations: bronze, iron, general trade, money, alphabetical writing and human slavery. Slavery dominated a large zone, the Mediterranean for example, for more than 25 centuries. The capitalist society lead to a new commercial, scientific and technological revolution and the general knowledge and dominion of the Earth. The 'capitalist event' happened at least twice in an independent way: in Europe and Japan.

The dates used in *Table 2* are the usually accepted dates. Now it is possible to support the intuition that general human history, not only technology or science, is in a kind of accelerated motion.

A numerical 'law'

A numerical 'law' is an useful tool to speculate about acceleration of history. *Table 2* suggests that time intervals between events are smaller and smaller. A simple inspection

TABLE 2. THE MOST IMPORTANT TECHNOLOGICAL EVENTS IN HISTORY (PERSONAL CHOICE)

Event	Possible date	Time interval
Hominid erect position	− 5 000 000	
Stone instruments	− 1 500 000	3 500 000
Use of fire	− 500 000	1 000 000
Abstract thinking	− 45 000	455 000
Agriculture and feudalism	− 9000	36000
Metalwork and slavery	− 1100	7900
Capitalist society	1200	2300

shows a kind of geometric progression. *Table 3* shows a geometric progression of decreasing intervals between relevant technological events. The dates are adjusted in order to match the figures in *Table 2*. Dates were also extrapolated in both directions in order to have a larger time-span. There is an impressive agreement between *Tables 2* and *3*, with the exception of a non-detected event 130 000 years ago. Please observe that there exists only one parameter to adjust: the ratio.

As the list of relevant events is extended into the past, two important new events appear. The dinosaur extinction is, in fact, the most important event in the history of the mammals. Of course it is not a 'technological event' except in a Darwinian sense. This will be made more clear in the following. The beginning of anthropoids, in this context, is the next important event. 19 million years ago is a good guess for that date. In an opposite direction, as the list is extended to the present, it is possible to detect in 1796 (perhaps!) the beginning of industrial revolution. Further on, this 'law' predicts a kind of 'Zeno process'. Time intervals become smaller and smaller, and finally we find a 'Zeno' limit date (when Achilles meets the tortoise!) in 2060. It is clear that this simple law cannot 'explain' the complete human society; the idea is only a tool for thinking about the future. As we will discuss, the 'Zeno limit date' may be a theoretical idea, not an actual limit to be reached.

Technology and human population

The basic question that we must answer is simple: why does history accelerate? This question is associated with the philosophical idea of progress. Different thinkers, in the past, have answered that question in different ways. Most of the answers need a God to explain the acceleration. In this paper, we propose a very straightforward answer. Human history accelerates because the human population is growing: there are more and more human beings on planet Earth.

Man is a technological mammal. Human beings now dominate the planet because they have tools. It is an odd kind of Darwinian evolution, different from the evolution of

TABLE 3. TECHNOLOGICAL HISTORY RECONSTRUCTED WITH A SIMPLE GEOMETRIC PROGRESSION OF DECREASING INTERVALS; THE DIVISION RATIO IS 3·46

Beginning of phenomena	Date	Interval
Dinosaur extinction?	− 65 154 980	46 325 526
Beginning of anthropoids?	− 18 829 454	13 388 880
Hominid erect position	− 5 440 574	3 869 619
Stone instruments	− 1 570 955	1 118 387
Use of fire	− 452 568	323 233
?	− 129 335	93 420
Abstract thinking	− 35 915	27 000
Agriculture and feudalism	− 8915	7803
Metalwork and slavery	− 1112	2255
Capitalist commercial society	1144	652
Capitalist industrial society?	1796	188
?	1984	54
?	2038	16
?	2054	5
?	2059	1
'Zeno' limit date	2060	

all previous living beings. The capability to develop new tools (that is technology!) depends on experimentation. The present tools are modified (possibly in a random way). The new tools are experimented with and selected in a new form of Darwinian survival. The great technological events are the result of an accumulation of small inventions, each one obtained by chance (good luck to find places, materials, forms, animals or plants). The faster the human population grows, the sooner all possibilities are explored. The answer we propose is simple: people are restless tool makers; more human beings means faster technological changes. The converse is also true. A better technology provides more possibilities of survival and that leads to an increase in the human population. This is a virtuous circle or a dialectical contradiction of a beneficial rather than destructive sort.

Mammals are the animals best adapted to inherit the dinosaurs' planet. Anthropoids were the mammals best adapted to discover tools. It needed 46 million years of mammals' 'natural experimentation' (i.e. Darwinian selection) to 'discover' an anthropoid. Hominids, which have free hands to work and develop tools, are the anthropoids best adapted to the technological revolution. It needed 13 million years of anthropoid 'natural experimentation' to 'discover' a hominid. It is an interesting observation that other mammals (dolphins, whales, etc.) while possibly possessing a comparable intellectual capacity with the hominids, were not capable of constructing material tools. This point shows the importance of material society and it is worthy of reflection. Hominids needed 3·8 million years to discover stone tools; early men needed only 1·1 million years to discover fire. What is the difference? The population of early men was bigger than that of the hominids. Hominids (as we actually know) lived in Africa; early fire men reached Europe and Asia. There were more of them, so they experimented more (because of quantity, not quality) and discovered a revolutionary technology three times faster.

Agriculture was discovered at least three times in the past. 7800 years later, in the first discovery place, slavery began (metal tools, money, slaves, etc. were discovered). We can ask: what is the contribution of China and America to the general human history? All those people were experimenting too. For example, Asiatic nomads discovered horse technology. China discovered powder, paper and the use of the lodestone. America discovered corn and potato. It was the illusion of El Dorado (a treasure accumulated by civilised Americans) that pushed oceanic navigation to become a reliable technology. Certainly it was useful to have a repeated discovery of agricultural technology, because different tools and objects were discovered and developed. All that technology eventually became part of the global capitalist society.

Science and technology are the collective result of all the human action. The Steppe nomad with the horse technology is as important as the civilised Mesopotamian with their cuneiform writing. The porter of their laboratory is as important the modern investigator. All contribute, direct or indirectly, to the Darwinian process of natural selection that drives technology and science. At this point, we can suppose that we have established with reasonable strength, a link between the history of technology and the global human population.

The evolution of human population

To go further in the investigation of the proposed 'law' and 'explanation', we must study global human population in history. In *Table 4*, several hypothetical human populations are presented.

TABLE 4. GLOBAL HUMAN POPULATION ESTIMATIONS (MILLIONS)

	Coale[2]	Huxley[3]	Keyfitz[4]	Livi-Bacci[5]
Palaeolithic ?	—	—	—	1
– 10 000	—	—	—	6
– 8000	5–10	4–18	10	10
– 4000	—	10–35	—	—
– 2000	—	30–70	—	—
Bronze age	—	—	—	100
1	300	100–200	—	252
1750	—	—	—	771
1950	3900	2000	2500	2350
Next century?	—	—	—	10 000

If we consider a present 5000 million population[5,6] we can test the population hypothesis. The results are presented in *Table 5*.

The figures in *Table 5* are plausible. The global Neolithic estimation is higher than the current estimate, but not impossible. The population estimate for early man is not known at present.

The 'Zeno effect' predicts an unbounded population growth in the near future. This prediction is not different from current catastrophic views. As we shall discuss later, the Zeno effect can be understood as a kind of super-technological event; near that critical date, the crude geometrical 'law' is no longer a good approximation.

An algebraic 'law'

The two geometric progression models can be presented in a more interesting way. The model is based on two main hypotheses:

- technological milestones are separated in time by a geometric, decreasing progression of intervals;
- human population grows according to the same geometric progression.

The geometric progression can be expressed as:

TABLE 5. GLOBAL HUMAN POPULATION ACCORDING TO THE GEOMETRIC GROWTH HYPOTHESIS

Beginning of phenomena	Date	Population
Dinosaur extinction?	– 65 154 980	
Beginning of anthropoids?	– 18 829 454	20 K
Hominid erect position	– 5 440 574	70 K
Stone instruments	– 1 570 955	243 K
Use of fire	– 452 568	842 K
?	– 129 335	3 M
Abstract thinking	– 35 915	10 M
Agriculture and feudalism	– 8915	35 M
Metalwork and slavery	– 1112	121 M
Capitalist commercial society	1144	418 M
Capitalist industrial society?	1796	1445 M
Present population	1984	5000 M

Note: K means thousands, M means millions.

human population	p	kp	k^2p	k^3p
time between milestones	a	a/k	a/k^2	a/k^3

Now it is simple to write the following equations:

$$t = \Sigma \frac{a}{k^i} = a \frac{k^{\frac{1}{n+1}-1}}{\frac{1}{k} - 1}$$

$$P = pk^n$$

From those equations we can eliminate the technological milestone and relate time t with human population P:

$$t = a \frac{\frac{p}{kp} - 1}{\frac{1}{k} - 1}$$

The resulting equation is a hyperbola; the vertical asymptote, at which population goes unbounded, is

$$t_\infty = \frac{ka}{k - 1}$$

It is interesting observe that the geometric progression does not seem to be something important in this process. The events that we called relevant accumulate a certain quantity of human work in exploration, experimentation and discovery. Once achieved, a work accumulation greater than some (unknown) limit is reached and a revolutionary event occurs; we could imagine this as an expression of the dialectical law of transition from quantity to quality.

It is more simple and expressive to present the population equation as:

$$(t_\infty - t)P = t_\infty P_0$$

where $P_0 = p/k$.

The event at time t_∞ is the next subject to study.

The super event

The acceleration of history seems to end, in different ways, in a common prediction: a super technological event some time in the middle of the 21st century. Do we have evidence to support the approaching catastrophe? Thinkers and common people have always predicted human final extinction or different kinds of catastrophes. What we claim is not new. Nevertheless we have, at present, some evidence of a new super technological event.

Science has detected some unavoidable technological frontiers:

- The speed of light is an absolute limit for transport and communications. Men are grounded to Earth. Stellar communications are impossible: a galactic dialogue, even

with the nearest stars, will require centuries. We have arrived at the limits of the exploration of the universe.

- Microelectronics has grown in a exponential way since 1960. We have not yet found a physical limit. There must exist a quantum limit and that may well be found some time in the next 50 years. This will be the end of the electronic revolution[11].
- Scientific instruments are reaching their limiting size. Telescopes, particle accelerators, microscopes are now at the budgetary and the physical frontier. We have arrived at the limit of the observation instruments for matter.

Some things are changing in the history of the human species:

- The human life span has been increasing in the last century. We have evidence that men are 'designed' by natural selection to live less than 40 years (the archaeological and historical human life span). Men older than 40 have vision difficulties, spinal-column problems; they loose their teeth, fertility and hair and have many other problems. It will take several thousand years to adapt to a 70 or 90 year life span, if medicine permits Darwinian selection to act freely.
- Planet Earth is destroyed and polluted in an accelerated way. Animals and plants species are destroyed in a irrational way. People begin to question technological advances. Some support the idea that technology must stop and civilisation must return to a 'natural' way of living.
- Developed societies stop population growth voluntarily. In those societies population begin to stabilise. This is something new for human population.

All this evidence supports the idea that we are approaching a super technological event, as most acceleration models predict.

When will the super event happen?

When will the super event occur? A crude Adams's 'law' predicts sometime between 2040 and 2070. We know that this estimation is noisy.

A crude geometric progression model predicts 2060. This figure is reasonably accurate. In order to adjust *Table 3*, we have only one parameter: the progression ratio. A very small change in this figure creates a great dispersion among the earlier dates.

Present demographic growth enables a better estimation, using the global population equation. If we derive the logarithm of the equation we obtain:

$$\frac{1}{P}\frac{dP}{dt} = \frac{1}{t_\infty - t}$$

The equation predicts a demographic increase in an accelerated way. In *Table 6*, recent estimations of global human population are presented.

The *Figure 1*·59% per year for 1990 also sets the date at 63 years later, that is 2053.

TABLE 6. PRESENT ACCEPTED RATE OF GLOBAL HUMAN POPULATION GROWTH

Date	Rate of growth
1957	1.60% per year[8]
1990	1.59% per year[6]

However, we notice that a prediction based on the growth rate in 1957 would give nearly the same time-interval from then. However, as world population growth currently seems to be decelerating, it is possible that the interval $(t_\infty - t)$ will increase, and so on this reckoning, the super-event will be deferred. We may say that we possibly have a good agreement of the super-event date, but it is not enough. It is impossible to support seriously this simple catastrophic idea. As history moves towards the super event, some things must change and the equations no longer remain valid. We must go deeper into the study of the environment of the super event.

The growth of capitalist society

Our last historical sequence is the penetration of the whole planet by capitalist society; we show that this process could be complete around the date of the Zeno-event. Then globalisation will be complete, with no frontiers, one global market and one global economy. This vision seems to be more and more accurate if we study the history of last centuries. This approach permits another super event date estimation. When will capitalist society be completely global?

A few historical notes will help to understand the problem. In the sixteenth century, capitalist Europe began the global conquest of the planet. The colonial system was the result, and it lasted until the world wars of the twentieth century. In the nineteenth century the idea of a new society, post-capitalist, was stated by socialist thinkers: notable among them being Marx[9]. In the present century, the 'new' society was put 'to work' (in the Soviet Union, China and several other countries). It is now clear that 'the experiment' did not work properly. In the last 30 years, a new kind of capitalist country has appeared: the so-called 'Asian tigers' (Taiwan, Korea, etc.). Now we can seriously ask when will capitalism dominate all the world?

The first step towards answering this question is to collect some data. In *Table 7*, we have several estimated data. We have made an estimation of the population living under a capitalist society and the related global human population. The estimation is the result of the sum of the population of countries supposed to be capitalist (in the opinion of the author) in the date considered.

Does the capitalist (or developed) society advance in its proportion of the global

TABLE 7. ESTIMATION OF POPULATION LIVING UNDER A CAPITALIST SOCIETY (MILLIONS)

Date	Capitalist population	World population	Percentage of world	Notes
1825	40	—	—	(1)
1914	296	1629	18.1	(2)
1951	527	2519	20.9	(3)
1979	1022	4293	23.8	(3)
1990	1209	5248	23.0	(4)

Notes:
(1) Includes England, Wales, Scotland, Holland, Belgium, Switzerland and half of the population of France. Figures are from *Précis de la Géographie Universelle*[10]
(2) Includes England, Wales, Scotland, Holland, Belgium, Switzerland, France, Germany, Italy, Austria, Hungary, United States and Japan. Figures are from *Enciclopedia Universal Ilustrada*[7].
(3) Figures are from United Nations[8]. Developed countries are assimilated to capitalist countries.
(4) Figures are from *World Almanac*[6]. Developed countries are assimilated to capitalist countries.

world population? It is commonly affirmed (without convincing proof) than poverty is increasing in the world. This pessimistic view states that in the Third World (or underdeveloped world) population increases faster than the economy. This position can be extracted from crude figures: it is hard to tell if, in the last forty years, capitalist society has made real advances in the world. The figures for the nineteenth century and the beginning of the twentieth century were usually not considered. For that reason, poor people in the world seem to increase. The answer to the question can follow from *Table 7* and a proper mathematical model. No answer is better than the model used to extrapolate the figures.

The global capitalist model

There are many world population models. In this paper, a new one is added. This model is a Markovian model with basically two states: a person lives in a capitalist country or in an underdeveloped country.

The following simple hypotheses are made:

- the capitalist economy is in exponential growth;
- the population in capitalist societies is in very slow exponential growth (or does not grow);
- the population in underdeveloped societies is in exponential growth;
- each year capitalist economy 'takes a piece' of the underdeveloped society, as permitted by economic surplus;

The model leads to simple mathematical equations:

$$D_{n+1} = kD_n$$

$$U_{n+1} = aU_n + (k - b)D_n$$

where: D is population in capitalist societies; U is population in underdeveloped societies; a is population growth rate in underdeveloped societies; b is population growth rate in capitalist societies; and k is global capitalist economy growth rate.

The parameters can be adjusted in order to approach the values of *Table 7*. The results are in *Table 8*.

This simple mathematical model gives a clear answer to the question of whether capitalist societies are growing because underdeveloped countries are changing into capi-

TABLE 8. MARKOVIAN ESTIMATION OF POPULATION LIVING UNDER A CAPITALIST SOCIETY (MILLIONS)

Date	Capitalist	World total
1825	10	480
1914	139	1860
1951	414	3158
1979	948	4580
1990	1313	5255

Note: The parameter values used for fit are: a = 1.016 (1.6% per year, typical growth of global population); b = 1 (no growth hypothesis); k = 1.030 (3% per year, typical growth of global capitalist economy).

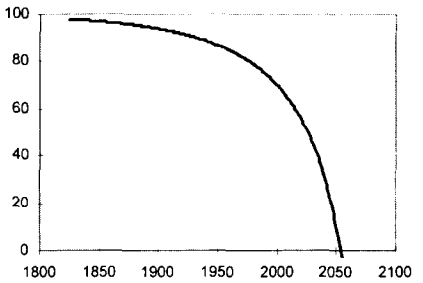

Figure 2. Percentage advance of the capitalist economy. The zone below the curve corresponds to the non-capitalist economies. It is notorious that the penetration is slow at the beginning (only 30% of the world toward the year 2000) and later on it becomes very rapid.

talism. This follows because the speed of growth of the capitalist economy is greater than the speed of growth of the human population. We can also have a precise date for capitalist economy to accomplish world domination. In 2053, there will be no underdeveloped countries in the world. The total population will be 8·67 billion people with zero growth.

Figure 2 shows the way the capitalist economy penetrates the world population. The final result is a world-wide capitalist economy, for which we should have to wait only until the second half of the 21st century.

The end of technological man

The different date estimations for the super-event are presented in *Table 9*. There is a general agreement: it will occur sometime in the middle of the 21st century.

What happens then? According to the various predictions, the capitalist economy will dominate the world, science and technology will be unable to grow further and the population curve will suddenly come off the asymptotic path and become stable. When the capitalist economy dominates the planet, the economy will lack the vital space in which to grow. As the basic assumption of capitalist production is exponential growth, the only way out is a crisis: it does not have new markets to conquer and it could not continue to sell everything which it manufactures. The science and the technology will not be capable of continuing producing new commodities or manufacturing techniques because of inherent technological limitations or lack of consumer demand. However, the rhythm that demands innovations (for capturing market share) needs to continue in its increase. This resembles some sort of general crisis of capitalist technology-based industry.

How the population will stabilise is not defined by our projections. It is conceivable that capitalism will adjust to a prosperous no-growth scenario, and the planet will carry

TABLE 9. ESTIMATED DATE OF SUPER EVENT

Method of estimation	Estimated date	Precision
Adams's law	2040 to 2070	Noisy
Technological history	2060	Very sharp
Population growth	2053	Sharp
Capitalist growth	2053	Fair

its population comfortably. On the other hand, the final conquest by capitalism might actually mean a 'global sweatshop economy', where all the masses toil for low wages and a small elite appropriates a large portion of the surplus value. This is standard in many 'developing' nations, and can be seen in the growing inequality of incomes and wealth in the USA. Such a situation could not be socially stable in the long run. We should recall that the ecological projections of the original Limits to Growth study predicted collapse in almost all cases.

At this stage, we can only speculate about the character of events around the 'Zeno-point'. Also, an awareness of the direction of trends early in the next century could lead to policies to modify them and avert their worst consequences. However, one conclusion from these studies seems well founded: that the sort of economic and technological activity that has brought us to our present state over many millenia, culminating in global capitalism, seems destined to encounter inherent limits within the next half-century. These could be considered as contradictions in the Hegelian sense, even deeper than those discussed by Marx. In that sense, we could speak of the end of technological man.

Notes and references

1. Mensch, G., *Stalemate in Technology*. Cambridge, 1979.
2. A. J. Coale, The history of the human population. *Scientific American* **231**(3), 40–51 (1974).
3. J. Huxley, World population. *Scientific American* **194**(3), 64–76 (1956).
4. N. Keyfitz, The growing human population. *Scientific American* **261**(3), 71–77 (1989).
5. Livi-Bacci, M., *A Concise History of World Population*. Cambridge, 1992.
6. Hoffman, M. S. (ed), *World Almanac*. New York, 1989.
7. *Enciclopedia Universal Ilustrada*. Espasa Calpe, Bilbao, 70 Vols.
8. United Nations. *Report on the World Social Situation*. United Nations, New York, 1957.
9. Marx, K., *Manifest der Kommunistischen Partei*. Friedrich Engels, Milano, 1984.
10. Malte-Brun, *Précis de la Géographie Universelle*, 4ème edn. Paris, 1836.
11. T. Lewis, The next 10,000(2) years, *IEEE Computer* **29**(4/5), (1996).