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Robert W. Kates

Population, Technology, and the Human Environment: A Thread Through Time

PLATO OBSERVED IT, THE OLD TESTAMENT TAUGHT IT, and Thomas Robert Malthus feared it. It has been called the principle of plenitude, which "presupposes a richness, an expansiveness of life, a tendency to fill up, so to speak, the empty niches of nature; implicit is the recognition of the great variety of life and perhaps its tendency to multiply."[1] For all living things, the biblical injunction is clear: "Be fruitful and multiply."[2] But for one species of life, humans, the injunction is clearer yet: "Be fruitful and multiply, and fill the earth and subdue it; and have dominion over the fish of the sea and the birds of the air and over every living thing that moves upon the earth."[3]

Malthus, a Christian cleric, worried over the injunction and conducted a thought experiment to demonstrate how disastrous its pursuit would be:

> . . . if the necessaries of life could be obtained and distributed without limit, and the number of people could be doubled every twenty-five years, the population which might have been produced from a single pair in the Christian era, would have been sufficient, not only to fill the earth quite full of people, so that four should stand in every yard, but to fill all the planets of our solar system. . .and the planets revolving around the stars which are visible to the naked eye.[4]

Thus, Malthus concluded, a benevolent Creator would limit in quantity "the necessaries of life" and temper the principle of plenitude by the principle of population.

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Malthus's principle of population begins with the living realities of hunger and sex, and the latter can be satisfied with greater ease than the former. Sex in Malthus's time was still linked to frequent reproduction, leading to a faster growth in the numbers of persons than in the means of subsistence. Unchecked, "the human species would increase as the numbers 1, 2, 4, 8, 16, 32, 64, 128, 256; and the subsistence as 1, 2, 3, 4, 5, 6, 7, 8, 9." The imbalance cannot continue, and indeed growth is reduced by "positive checks" in the form of misery (famine, war, and disease) and vice (prostitution, homosexuality, adultery, birth control, and abortion) and—in revisions of his original *Essay on the Principle of Population*—by "preventive checks," primarily, delayed marriage.

Malthus was born in 1766, late in a century in which England and Wales almost doubled in population from 4–5 million to 9–10 million. Yet public controversy about human numbers raged in British intellectual circles until the first census of 1801, with many believing that Britain was losing population while it actually gained.

Educated by his father and tutors of independent mind, Malthus entered Cambridge in 1784 and graduated with honors in mathematics.[5] Like many scientists and intellectuals of his generation, he became both a university fellow and an Anglican priest. He published his *Essay* anonymously in 1798 at the age of thirty-two, while serving as curate at a small country chapel.[6] In Surrey, in the village of Oakwood, Malthus presided over numerous baptisms and may have directly observed the rapid growth of the English population. Death was also known, and Adam Smith, the most powerful intellectual influence on Malthus, had written in *The Wealth of Nations* (1776) that

> in some places one-half of the children born die before they are four years of age; in many places before they are seven; and in almost all places before they are nine or ten.... Every species of animals naturally multiplies in proportion to the means of subsistence, and no species can multiply beyond it. But in a civilized society it is only among the inferior ranks of people that the scantiness of subsistence can set limits to the further multiplication of the human species and it can do so in no other way than by destroying a great part of the children which their fruitful marriages produce.[7]

Still, the sources of inspiration for Malthus are not obvious. Of course, other limits to population had been observed. Some 1,600 years previous, Tertullian, a Carthaginian resident in Rome, wrote:

> Surely, it is obvious enough, if one looks at the whole world, that it is becoming better cultivated and more fully peopled than anciently.... No longer are savage islands dreaded, nor their rocky shores feared; everywhere are houses, and inhabitants, and settled government, and civilized life. What most frequently meets our view is our teeming population; our numbers are burdensome to the world, which can hardly supply us from its natural elements; our wants grow more and more keen, and our complaints more bitter in all mouths, whilst nature fails in affording us her usual sustenance. In very deed, pestilence and famine, and wars, and earthquakes have to be regarded a remedy for nations, as a means of pruning the luxuriance of the human race.[8]

Firmly setting one pole of a profound disagreement that persists to this day, Malthus published partly in response to the utopian visions of human perfection offered by his contemporaries, such as William Godwin and the Marquis de Condorcet.[9] Against their confidence in human institutions and ingenuity, Malthus invoked the hard arithmetic and biological and environmental determinism of the principle of population.

All of us who ponder the questions of the human environment are the intellectual descendants of Thomas Robert Malthus. Whether "neo-Malthusian," "anti-Malthusian," or simply agnostic, we explore the equation of population with resources and technology, which distills the problem of the human environment. Over time the focus of Malthusian concerns has shifted. In 1798 the key ratio in the Malthusian equation was food and farmland per person. By the 1850s, the resource term expanded to include energy and other materials, urgently argued in the classic volume of British economist William Jevons on the coal question.[10] By the middle of the twentieth century, the United States would discount fears about resource scarcity and promote a new Malthusian numerator that included amenity resources and the pollution-absorbing capacity of the environment.[11] The UN Stockholm Conference on the Environment in 1972 enlarged such concerns to a global scale and drew attention to the basic life-support systems and the chemical cycles of the biosphere. More recently, losses in the diversity of life and genetic information have joined the earlier concerns.

Characteristically, none of the earlier Malthusian concerns really disappear but are renewed in some larger, more international context. And for each of the different notions of critical resources, technology will make possible new reserves and new substitutions and in turn cause new problems. Thus, a continuous process of Malthusian refutation and renewal has marked the two centuries since publication of the *Essay*. In my own professional life, I have participated in two and a half cycles of research and argument. Currently, I am trying to understand the roles of neo-Malthusian scientific "Jeremiahs" and society's response to them by examining the post-World War II history of jeremiads,[12] beginning with Vogt's[13] and Brown's[14] concerns with population growth, moving on to subsequent fears about food, materials, energy, and toxic pollutants, and concluding with the formal synthesis of concerns in *The Limits to Growth*.[15]

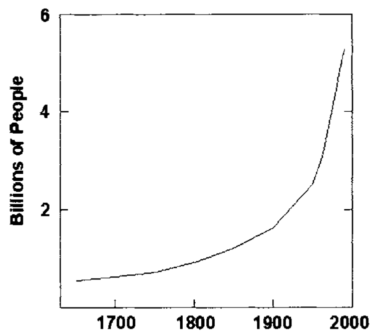
Over time, the population denominator has increased from a local to a national, regional, and then global scale. The requirements of each person also change over time, from the meager demand typical of Malthus's day to the copious consumption of the wealthy fifth of the present world population.[16] Contrasts with the modest per capita usage of most residents of the less-industrialized countries show how levels of affluence and types of technology modify the Malthusian equation.[17]

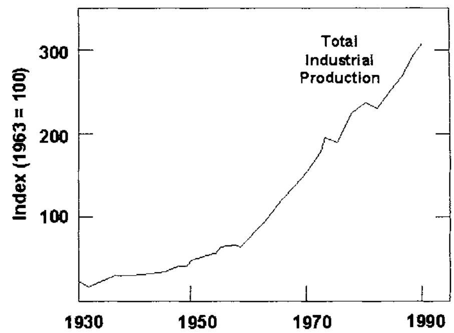
Yet beginning with the genus *homo*, the numbers of people form a continuous thread through time with which to examine the warp and woof that pattern our environment. Thus, in this essay, I employ a sequence of four temporal frames—ages, millennia, centuries, and decades—to examine the dynamics of population, resources, and technology. Each frame highlights significant questions about the sources of technological change; the growth, decline, and stabilization of human populations; and the extraordinary challenge posed by the dynamics of the current period.

AGES: TECHNOLOGICAL REVOLUTIONS AND POPULATION SURGES

A few years ago, I had the opportunity to review *Beyond the Limits*,[18] the sequel to *The Limits to Growth*.[19] In the words of the

Figure 1. World Population. Figure 2. World Industrial Production.





authors, "human uses of many essential resources and the generation of many kinds of pollutants have already surpassed rates that are physically sustainable."[20] The first figures in the book contain the familiar curves of exponential growth over several centuries of world population and, during this century and more fitfully, industrial production (see *Figures 1* and *2*). These the authors generalize, stating that "Exponential growth is the driving force causing the human economy to approach the physical limits of the earth."[21]

While I suspect that many who casually encountered that statement might agree with it, I experienced a deep uneasiness with this frequently-used mental graphic of the future. Having assimilated, as a graduate student, a different image of population pathways, past and future, as S-shaped curves growing to limits, I was left forever skeptical of the exponential vision. In a 1960 article, ecologist Edward Deevey had pointed out two defects in the commonly accepted picture of the growth of the population shown in *Figure 1*. First, the basis of the estimates, back to about A.D. 1650, is rarely stated. Second, the scales of the graph are chosen so as to make the first defect unimportant. In Deevey's words, "The missile has left the pad and is heading out of sight."[22]

To remedy this situation, Deevey collected the then-available estimates of population over hominid existence and plotted these on logarithmic scales to emphasize ratios rather than absolute numbers. These curves and more recent data are shown in *Figure 3*. Deevey explained that:

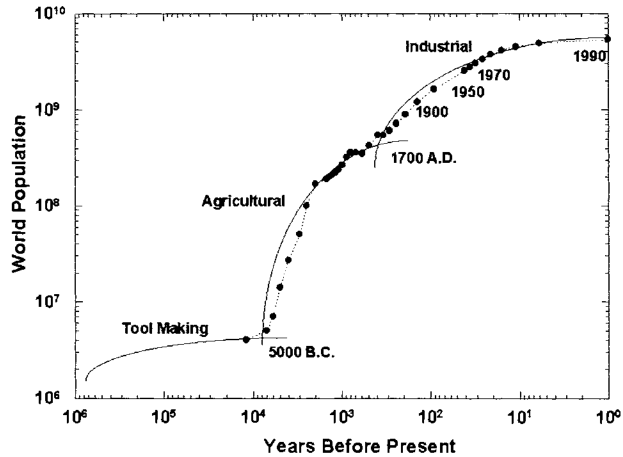
> The stepwise evolution of population size, entirely concealed with arithmetic scales, is the most noticeable feature of this diagram. For most of the million-year period, the number of hominids, including man, was about what would be expected of any large Pleistocene mammal—scarcer than horses, say, but commoner than elephants. Intellectual superiority was simply a successful adaptation, like longer legs; essential to stay in the running, of course, but making man at best the first among equals. Then the food-gatherers and hunters became plowmen and herdsmen, and the population was boosted by about sixteen times, between 10,000 and 6,000 years ago. The scientific-industrial revolution, beginning some 300 years ago, has spread its effects much faster, but it has not taken the number as far above the earlier baseline. The long-term population equilibrium implied by such baselines suggests something else. Some kind of restraint kept the number fairly stable.[23]

According to Deevey, human population has surged greatly three times. The first was associated with the toolmaking or cultural revolution, lasted about a million years, and saw human numbers rise to five million. The second saw the population swell a hundredfold to about five hundred million people over the next eight thousand years, following the domestication of plants and animals and the invention of agriculture and animal herding. In Malthus's lifetime, early in the industrial revolution, it doubled again to the first billion. With a current world population of 5.7 billion, we are in the midst of the final doubling of this, the third great surge of the population. World population is projected to increase to more than eleven billion before leveling off again—some three to four hundred years after the scientific-industrial revolution began.

These toolmaking, agricultural, and scientific-industrial revolutions each transformed the meaning of resources and increased the carrying capacity of Earth. Each made possible a period of exponential growth followed by a period of approximate stability, as the record of human existence reveals in the frame of ages.

But if this is the record, the causes of such technological change are not as clear. Consider, for example, the origins of agriculture. Intentional farming for food or subsistence dates back nine thou-

Figure 3. World Population with Three Growth Pulses.



Note: Updated and redrawn from Edward Deevey, "The Human Population," *Scientific American* 203 (1960): 194–204.

Sources: United Nations, *World Population Prospects: The 1992 Revision* (New York, United Nations, 1993); C. McEvedy and R. Jones, *Atlas of World Population History* (New York: Penguin, 1985); and Edward Deevey, "The Human Population," *Scientific American* 203 (1960): 194–204.

sand years. Agriculture evidently began independently in the Near East between eight thousand and nine thousand years ago for wheat and barley, eight thousand to seven thousand years ago in China for millet and rice, and eight thousand to sixty-five hundred years ago in the Western Hemisphere for squash and maize.[24] Agriculture and its pastoral cousin gradually replaced a system of food gathering and hunting that had apparent advantages of less work and better diets.[25] Why? The short answer is, "We do not know"; the longer one begins, "We have theories."

In general, the many explanations emphasize either push or pull factors. The pushes to agriculture are primarily said to be population increase and environmental change. Human communities six thousand to nine thousand years ago turned to agriculture because their numbers increased beyond the carrying capacity of their accessible resource base, or the resource base was reduced by environmental (climatic, biological, or human-induced) changes, or both. The pulls highlight the attractiveness of agricultural technology (or the agrarian life-style) in increased yields per hectare and in the ability to store resources, thereby reducing annual and seasonal variation in the food supply. Thus, human communities encountered wild precursors of domesticated plants and animals; gradually learned about their availability, reproduction, and life cycle; and then experimented, intentionally or incidentally, with their selection, growth, harvesting, and use.

Within push and pull there are many variants as well as hybrid explanations that emphasize one factor or another in a dynamic sequence. A coevolutionary explanation even argues against the independence of human agency implied by both push and pull theorists.[26] Instead, it offers the perspective of the domesticated plants and animals and their seeming reproductive success by encouraging humans to domesticate them, a quite different view of humans in nature.[27]

Influenced by the Danish economist Ester Boserup,[28] demographer Ronald Lee attempts to transcend the particular explanations for each of the great Deevey revolutions by integrating the theoretical insights of the

> ... two grand themes in macro-demographic theory: the Malthusian one, that population equilibrates with resources at some level mediated by technology and a conventional standard of living, and the Boserupian one, that technological change is itself spurred by increases in population. The striking association between the levels and changes in technology and population over the past million years leaves no doubt in my mind that at least one of these views is correct. But it is also possible that both are, since the two theories are not contradictory, but rather complementary. They share the assumption of diminishing returns to labour for a fixed technological level. To this common ground Malthus adds the assumption that population growth rates are endogenous, while Boserup adds the assumption that technological change is endogenous.[29]

Lee develops the broad qualitative features of a dynamic system governed by the mechanisms of both Malthus and Boserup and applies it to the Deevey diagram, asking how the transition between technological revolutions might be made. Lee defines a Malthus space in which, for a given level of technology, population grows; and a Boserup space in which, for a given level of population, technology grows:

> . . . for any state of technology, there are some ranges of population size within which technological progress occurs, and others where it does not. For any given state of technology, Malthusian forces will steer population size towards some equilibrium level. Common sense suggests that the behaviour of the system will depend critically on whether this Malthusian equilibrium population size falls within the range leading to further technological advance, or within the range leading to technological regression, either because the population is too small or too large.[30]

Lee sees the great technological revolutions as three distinct or weakly connected domains, each constrained by Malthusian equilibria.

To explore the theory, Lee considers the ability of cultures to leap across to other distinct technological regimes or pass through the bottleneck of weakly connected ones. He addresses the puzzling failures of China, more technologically advanced than Europe, to move early into the industrial revolution, and of Africa to move beyond hoe agriculture. These, Lee speculates, might be explained by Africa having too few people to force needed levels of technological intensification. And China, with too many people to accrue the surplus needed to invest in the crucial technology, perhaps found itself limited to mid-level technologies that the Europeans, with greater investment, repeatedly improved upon.

The complex and seemingly endless discussions on the origins of agriculture in archaeology, anthropology, biology, demography, economics, and geography, and the effort by Lee to develop an integrative theory, suggest two conclusions. Intense study has not yielded ready, simple, or consensual explanations as to the causes of the great technological revolutions. The most credible explanations depend on historical detail, multiple causes, and dynamic forces. They also yield a question about the driving forces of technological trajectories, such as decarbonization and dematerialization, documented elsewhere in this volume.[31] Is there some push of necessity that drives these forces, some teleological pull of technological superiority or economic efficiency, or some coevolutionary process of the natural selection of technologies within the human environment?

MILLENNIA: WHAT GOES UP MAY COME DOWN

Although the graphic message of the ages for the entire Earth is three great logarithmic arcs, the message of smaller frames differs. Reconstructing the population of regions over thousands of years, we find what my colleagues and I have called "millennial long waves." It is not surprising, after all, that societies might have some long harmonics, considering the range of time scales reported for the diffusion of various ideas and technologies.[32]

These population reconstructions grew out of an effort to examine how the time scales of human societies match other processes in nature, with many cycles of human activities contained in lifetimes or generations and those of the environment extending also to centuries and ages. We sought to compare the longest continuous place-based sequences of human activity that we could construct and to relate these, in turn, to environmental change. We were able to do this for four regions: the Egyptian Nile Valley, the Tigris-Euphrates lowlands, the Basin of Mexico, and the central Mayan lowlands of Mexico and Guatemala.[33]

These regions range in size from the compact Central Basin of Mexico of about 7,000 km^2 to the extensive Tigris-Euphrates lowlands of about 55,000 km^2. Their durations span the six-thousand-year reconstruction of the Nile Valley and the three thousand years of the central Mayan lowlands. The area of each region was selected on the basis of the congruence between a particular culture and a distinctive physical environment in the earliest period of the reconstruction and was then kept constant through the entire reconstruction. The duration of each reconstruction was based on the ability to meld archaeological and historical data to create a long-term sequence of estimated population. Methods involved the conversion of both archaeological material (e.g., ceramic or habitation remains) and documentary (tax or census) records into site-specific population estimates. Because for the most part we used estimates drawn from the work of other researchers, we selected between competing estimates based on our judgment of their demographic probability, quality of source data, and the validity of estimation techniques employed. Where needed, we inferred missing values for key time intervals.

The reconstructed population series are shown in *Figures 4* and *5*. They evidence both growth and decline; in none is population growth simply upward and onward from the cave. To highlight and compare major episodes of growth and decline and to distinguish these from fluctuations that were minor or artifacts of the estimation methods, we adopted a convention of considering only variations in growth in which the population at least doubles from its preexisting base, or is in decline in which it is minimally halved from its intervening apex. (This is akin to the risk assessment convention that considers as risk factors only those that at least double the observed risk.) With this criterion, each record is divided into intervals that we have designated as millennial long waves (shown as MLW I or MLW II in *Figures 4* and *5*).

In all except the Mayan case (the shortest record), the reconstruction shows two waves in which the population at least doubled over the previous base and then at least halved from that high point, as well as the rising part of a third wave. While the waves are all very long, they decrease in duration. The first waves average about 3,600 years in length, the second about 1,500 years, and

Figure 4. Tigris-Euphrates and Egyptian Population.

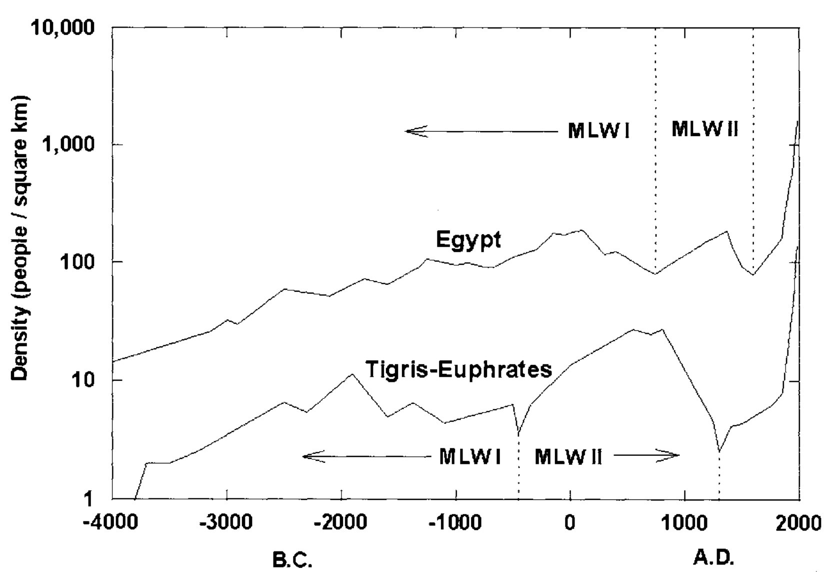
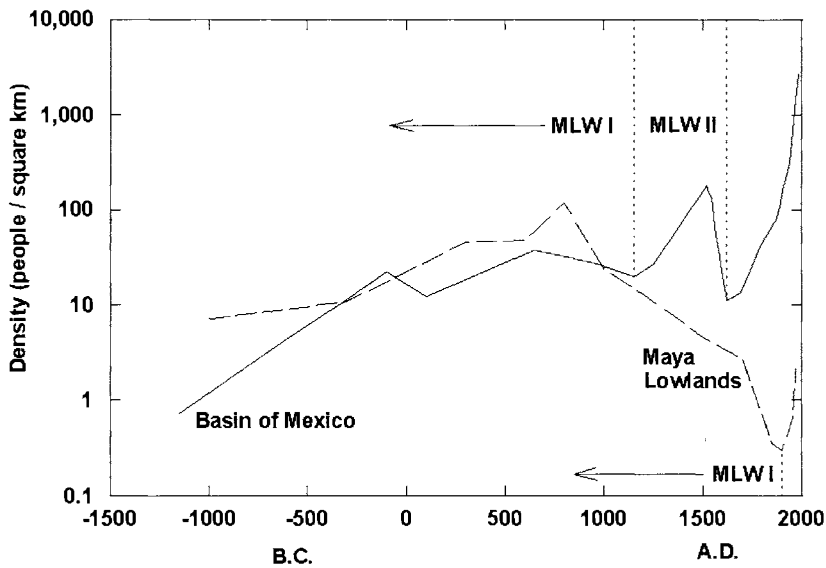


Figure 5. Mexican and Mayan Population.



the growth phase of the third waves, still in progress, averages 380 years to date. Growth phases last longer, occupying about 70 percent of the reconstructed time period. Rates of growth increase over time, averaging for the first waves 0.14 percent per annum, for the second 0.30 percent per annum, and for the modern period 1.43 percent per annum. The decline phases, while shorter and surely catastrophic, are not exactly precipitous. The second waves, for example, average more than five hundred years in duration even though they include one of the most precipitous population drops in human history—the sixteenth-century die-off of the native peoples of the Americas—whose immediate cause was epidemics of infectious disease.

What drives such long waves of increasing frequency and great amplitude? Again, we do not know, but we have theories. For one case,[34] the Tigris-Euphrates lowlands, we compiled a parallel reconstruction of major social, technological, and environmental events. We found no simple correlation between population growth and decline in the Tigris-Euphrates flood plain and periods of state formation, war, and empire collapse, or technological or climatic change. Rather, the interaction of the social, technological, and environmental events may cause the long-term population growth and decline. A simulation model has plausibly reproduced some of those interactions.[35]

The long waves of growth and decline disappear at the global scale of ages, as seen in the graph of logarithmic growth and stabilization (see *Figure 3*). Presumably the fate of particular places is averaged out. Some grow, others decline, but the overall tendency is growth. Has the scientific-industrial revolution, with a global economy and a global famine response system, exempted us from the Malthusian collapses of the past? Or can the collapse of particular regions, including regions that are world leaders, still occur in the modern world?

The millennial perspective offers no encouragement for an exemptionist doctrine. Indeed, by way of a thought experiment, I have tried to develop reasonable, albeit imaginative, decline scenarios for the current third wave still in its growth phase. The growth phase is projected to end in the 2060–2080 period, a time when current long-term demographic projections find that the relevant national populations will have accumulated 95 percent of their hypothetical equilibrium population. The duration of the decline of the third wave is estimated to be 0.65 of the growth phase, based on historic ratios. An average decline period of about three hundred years would then follow the 2060–2080 peak. We could consider, therefore, scenarios such as these:

> *Egypt*: The Nile Valley population peaks in 2080 at about 110 million people then begins a sharp decline. Three factors contribute to the decline: the development of a mechanized agriculture outside the valley that competes for Nile water; the suburbanization of Cairo; and most importantly, the recurrent bouts of MAIDS fever, the molluscan autoimmune disease.
>
> *Tigris-Euphrates*: The city of Baghdad and the dams and weirs of the Tigris-Euphrates are targeted in the second war with the Elamite Democratic Republic and are never rebuilt.
>
> *Basin of Mexico*: Repeated attempts by six successive Mexican governments to decentralize government, industry, and services outside the Basin of Mexico fail, and Mexico City becomes the largest

city in the world. However, a succession of disasters—beginning with the Great Vulchemical Smog of 2112 and ending with the Earthquake of 2119, which leaves 35 percent of the buildings uninhabitable—finally leads to the relocation of the capital to the site of the ancient city of Monte Alban, 250 miles southeast.

Mayan Lowlands: Clearing the central Mayan lowlands has newly revealed two major ancient urban sites at Uaxtum and Real Azul as well as reduced the habitat of rare birds. Through an initiative of the Organization of Central American States, the first trinational archaeological and biological park in the world is created for tourism, research, and wildlife conservation. In all, 22,715 km^2 are purchased in Belize, Guatemala, and Mexico and set aside for this purpose. Beyond the required staff no permanent inhabitants reside in the park after relocation.

CENTURIES: FROM HIGH BIRTHS, HIGH DEATHS TO LOW BIRTHS, LOW DEATHS

In the 1760s, the decade of Malthus's birth, England and Wales grew by 7 percent; in the 1790s, the decade of the first edition of his *Essay,* they grew by 11 percent. Three editions later, as Malthus neared death in 1834, decadal population growth had peaked at 18 percent—a veritable explosion.[36] The driving force behind the growth was primarily the decline in death rates. Thus, to have a decline in growth, birthrates also had to decline. Even as Malthus wrote the first *Essay,* the birthrate had declined in France by about 10 percent. Yet it would take almost a century more to decline in England and Wales and more than a century for all of Europe.[37] An emigration of fifty million people was also important in balancing European births and deaths. This transition from high births and high deaths to low births and low deaths took about 150 years to complete in England and has become the classic episode for population study. Demographers call it, not surprisingly, "the demographic transition."[38]

Yet here, too, much is unknown or in dispute. The transition clearly coincided with a profound shift from a rural agrarian society to an industrialized economy. Conditions changed drastically, particularly for infants and children, and wealth and education increased. But the reasons why the number of deaths declined when and as they did are not truly understood.[39] In our age of medical miracles, it is easy to presume that improved health care and prevention, including immunization, resulted in the decline. But the death rate began to decline long before the knowledge and practices of modern medicine evolved.[40]

The postponement of death and the concomitant transition from high death rates to low death rates seem related to three different sources of disease.[41] Before a society advances far in the demographic transition, most people die from infectious disease, although some diseases are intimately related to hunger. Early in the transition, deadly epidemics of infectious disease are moderated or disappear. These are diseases that you "catch" from food or water, or from another person, a rat, or a fly. The infectious agent may not normally live in our midst but, when present, can infect both the well-fed and the hungry. Such diseases include bubonic plague, malaria, measles, smallpox, typhus, and yellow fever. They recede in the face of quarantine, spraying, vaccination, sanitary practices, and, to some degree, through a growing immunity within the population. Thus some diseases, measles and chicken pox, become children's diseases; the rest of us have already had them. In England this part of the decline began as early as the 1670s, when plague seemed to disappear.

More stubborn are the infections from the endemic diseases, for which the sources of infection are ever present. Pneumonia, tuberculosis, and diarrhea are propagated by malnutrition, crowding, and poor sanitation. Progress against these diseases requires improvements in diets and living conditions.

Finally, deadly infections are replaced by the noninfectious diseases, the so-called diseases of civilization: heart disease and cancer. But by this time the death transition is over, and these are diseases of aging. Life expectancy is at least seventy years, and 1 percent or less of the population will die each year.

The decline in births lagged behind the decline in deaths, but in Britain both changes followed industrialization, as the society moved from an agrarian to an urban base. Thus, many scholars associate the decline in births and deaths with modernization or development.[42] Scholars differ on which elements of development would encourage the decline in births—the changing economics and usefulness of family labor, the improved security of family size with reduced infant and child deaths, or greater knowledge and interest in birth control resulting from education, particularly of women. Whatever the reasons, fertility began its decline in most European countries between approximately 1880 and 1930, first in Belgium and ending in Ireland.[43]

In many countries, including Belgium, England, Germany, and Switzerland, the development process was well under way when birthrates began to decline, lending support to the theory. But in others, including Bulgaria, Hungary, Italy, and Spain, birthrates turned downward while the societies remained predominantly agrarian and illiterate. Indeed, France began its decline before its industrial revolution. And in all European countries, births turned downward while infant mortality remained high, as high as the highest rates anywhere today or higher; so high rates of child survival were not a prerequisite of the decline.

While the empirical facts of the demographic transition are clear, the causes—even in the best-studied historical cases—are not. In the demographic transition now under way among the three-quarters of the world population found in developing countries, opportunities exist for both better understanding and further complication by virtue of the added conscious effort to influence the transition, a factor absent in the case of Europe.

For nations now in demographic transition, the process is also more rapid. The United Nations' first long-range projections of world population forecasted a population of 3.8 billion by 1975 based on medium assumptions.[44] Underlying the UN projection was an expectation that the birthrate in 1975 would be 37 for each 1,000 persons and the death rate 17 per 1,000. The actual population in 1975 was 4.1 billion, close enough, but births stood at 30 per 1,000 and deaths at 12. Both birth- and death rates had dropped faster than experts expected and history foreshadowed. It took a hundred years for deaths to drop in Europe, whereas the drop took thirty years in the Third World. Today the global transition to the level required for stability is more than halfway between the average of five children born to each woman during the mid-century height of population increase and the 2.1 births that would eventually achieve zero population growth. Current births average about 3.1.

The global death transition is more advanced. Life expectancy has transited more than two-thirds of the way between a life expectancy at birth of forty years to one of seventy-five, and it is currently sixty-six years. What do we know about the causes of this transition? Experts widely agree on the effectiveness of control of the epidemic and endemic diseases and overall improvement in nutrition, sanitation, and public health in the developing countries. Life expectancy in high-death countries rises most rapidly from improvements in child survival; these have been quick, impressive, and, once begun, seem to continue even during stagnation in economic and social development. Much of the improvement has been intentional, a conscious application of nutritional and public health measures in developing countries using modern health care research and disease control technology. Unlike much current medical technology, applications such as immunization, diarrheal control, malarial control, smallpox eradication, and child nutrition have been both effective and relatively low cost.

It is characteristic to be in the midst of change and not recognize it. As mentioned, while Malthus wrote his *Essay*, his contemporaries debated whether the population of England was growing or declining. So, on the eve of the 1974 World Population Conference in Bucharest, a leading demographer, Ansley Coale, found little evidence of a fertility decline in the developing world except in several small countries with populations of Chinese origin.[45] We now know that birthrates decreased in the decade from 1965 to 1975 by about 13 percent, with declines occurring in 127 countries.[46] By the time of the conference, the birth decline phase of the Great Transition was already under way.

The conference brought together representatives of 136 countries. The United Nations had declared 1974 to be World Population Year, and the Bucharest meeting capped it. The meeting, despite the polite consensual rhetoric of its final statements, showed a profound split between the First World of industrialized countries, on one side, and the Third World of developing countries allied with the Second World of socialist countries, on the other.[47] Most conferees agreed on the need for a decline in population growth but split in their assessment of the requirements for the transition. A phrase of an Indian delegate, "Development is the best contraceptive," was the rallying cry for the Third World countries. Lack of development encouraged large family sizes, and social and economic development would bring, as it had in Europe, a decline in fertility and population growth, even without organized government population programs. Arrayed against these arguments were most Western European countries (except France and Italy), Canada, the United States, some Latin American countries, Australia, Japan, and Iran. While acknowledging the need for development, they advocated independent and organized efforts to reduce fertility and argued that such successful efforts would in turn lead to development itself. Implicitly, the nations argued over two of the three major explanations for the rate and timing of the demographic transition: was it development or the access to modern knowledge and techniques of contraception that reduced family size?

A third major causal factor remained unspoken—culture and ethnicity. Such differences, whether real or not, were not discussible within the confines of the United Nations. Coale and others had noted, however, that the transition was most noticeable in countries populated by Chinese or those of Chinese origin, suggestive of the anomalous and pioneering role of France in the transition in Europe. Feminism was also largely unrecognized at the Bucharest Conference, as was the impact of changing education, employment, and roles for women.

At the September 1995 UN Cairo sequel to Bucharest, experts, including many women, demonstrated how such changing roles contribute to a fertility decline—although, as with the European transition, much still puzzles us. For example, it is not much clearer today which aspects of development most encourage lower birthrates in Africa, Asia, and Latin America than it was in the European decline. Analysts now choose from at least four arguments:

Less need for child labor, more need for educated children. As a society shifts from rural agrarian to urban industrialized, the potential contribution of children to family welfare and costs changes. The need for child labor lessens as does the role for children in providing old age security. Parents also make bigger investments in each child's health and education and expect greater returns to those investments in their future earnings. More care, energy, and money is spent on fewer children.

Less need for more births because more children survive. As the death transition proceeds, families realize that they can have the desired family size with fewer births since the chances of children surviving have increased.

Less time for childbearing and rearing, more time and need for education and work. As opportunities improve for women to have access to education and to work outside the household, marriage is delayed, and fewer births result from each marriage. Education and work compete for time with childbearing and provide alternative sources of reward and esteem.

More access to birth-control technology to achieve fewer births. Widely available, adequate, low-cost technology helps control the timing of conception. Access to such technology fulfills often longstanding desires for smaller families.

Of course, changing needs for labor, greater child survival, improved opportunities for women, and access to birth control all seem to proceed together in the course of development.

The protagonists in Bucharest and Cairo, however, cared less for the details of development than the distinction between development and organized family-planning efforts. Thus, much research has focused on seeking to estimate the relative contributions of economic and social development and organized family planning programs to the decline in births.

In comparing countries or regions, measuring development and characterizing family-planning programs are difficult. Even harder is disentangling the effects of development and organized family-planning programs since obviously they are strongly related. Development encourages people to use family-planning services. Indeed, organized family-planning programs are part of development, a natural occurrence in the provision by modern societies of health and welfare programs. Also, development creates the skilled people, transportation, access points for services, funding, and overall efficiency needed for effective programs. In turn, the results of effective family-planning programs might, over time, contribute to further development.[48]

Attempting to control for these interactions, several cross-cultural studies, covering ninety-four or more countries,[49] have found that increases in development are strongly associated with a decline in the birthrate and in fact account for about two-thirds of the decline. And over and above development—or even the way development makes programs more effective—organized family-planning programs make an additional difference of 15–20 percent. But even this amount is disputed, with other analysts claiming that at most 5 percent of the fertility decline results from such efforts.[50]

Only a few studies include other factors of culture and ethnicity. Yet if one looks further at the first ninety-four countries studied, taking the top twenty that recorded 20 percent or greater declines in births (compared with the overall world average of 13 percent), almost half the countries are in East or Southeast Asia, and a quarter are in the Caribbean. Of the top twenty, more than half are small island or city states. By numbers of population, Chinese speakers in China, Taiwan, Hong Kong, Singapore, and Malaysia predominate. Thus, one might add that when socioeconomic development and substantial family-planning programs are carried out in East and Southeast Asia, on small and crowded island or city states, or among those of Chinese extraction, more rapid declines take place.

Understanding the causes of fertility decline is not simply a scholarly undertaking but a pressing concern since the transition may have stagnated in the last decade. In fifteen countries, thirteen of them in Africa, birthrates apparently rose between the 1960s and the 1980s. In another twenty-three countries, the birthrate fell by less than 2 percent. In the 1970s total fertility dropped by 14 percent worldwide, in the 1980s by less than half that rate.[51] Both China and India had recent censuses and found higher populations than projected: seventeen million in China and four million in India. However, the recent Nigerian census found many fewer people than anticipated.

Cutting the average number of children that women bear from six to four has proven relatively easy in many developing countries. Further reduction, however, has been hard. The reasons may involve reduced political support in some countries (especially in the Near East, with the rise of religious fundamentalism); reduced spending because of debt-related cutbacks in health, education, and family planning; and the general slowing of development through the widespread economic stagnation of the 1980s and 1990s. Even more important, given the limited confidence in forms of social security outside the family unit, four may be the number of children actually desired in many parts of the developing world, and much of the previously unmet need may have now been met.[52] Finally, some scientists believe in African exceptionalism—that in Africa cultural, religious, and economic reasons encourage high fertility rates as much as East Asia seems to favor reductions in fertility.[53] Countering these trends is the renewed momentum to limit births in China, promising changes in fertility decision-making in South India, and the first significant drops in fertility in several Southern and Eastern African countries.[54]

DECADES: THE CHALLENGE OF THE GREAT CLIMACTERIC

We may well be in the final phase of the demographic transition of the scientific-industrial revolution, but from the perspective of the decades ahead, this is surely the Great Climacteric. At least that is how Ian Burton and I viewed it a decade ago:

> A climacteric . . . is a "critical period of human life" and a "period supposed to be specially liable to change in health or fortune" (*Oxford English Dictionary*). The term is normally applied to the individual; but as applied to population, resources, and environment throughout the world, it aptly captures the idea of a period that is critical and where serious change for the worse may occur. It is a time of unusual danger.[55]

In an extraordinarily short interval—a matter of decades—human society will need to feed, house, nurture, educate, and employ as many more people as already live on Earth. For this task, Deevey's interpretations of the past provide little comfort. A hundredfold increase in population marked past technological revolutions. The current multiplication is projected to be only two or perhaps three times, but we travel the trajectory within the span of a human lifetime.

Notwithstanding a wide range of estimates of how many people Earth can support,[56] for many of today's Jeremiahs a world of more than five billion people is already overpopulated. Ecologists Anne and Paul Ehrlich assert:

> The key to understanding overpopulation is not population density but the numbers of people in an area relative to its resources and the capacity of the environment to sustain human activities: that is, to the area's carrying capacity. When is an area overpopulated? When its population can't be maintained without rapidly depleting nonrenewable resources (or converting renewable resources into nonrenewable ones) and without degrading the capacity of the environment to support the population. . . . *By this standard, the entire planet and virtually every nation is already vastly overpopulated.*[57]

Many of us believe that if population growth can be held to some reasonable number, then sufficient food can be produced, even in a more crowded and warmer world. Yet this hopeful view has to grapple with two likely, connected realities: while population may more than double, production and consumption should more than double.

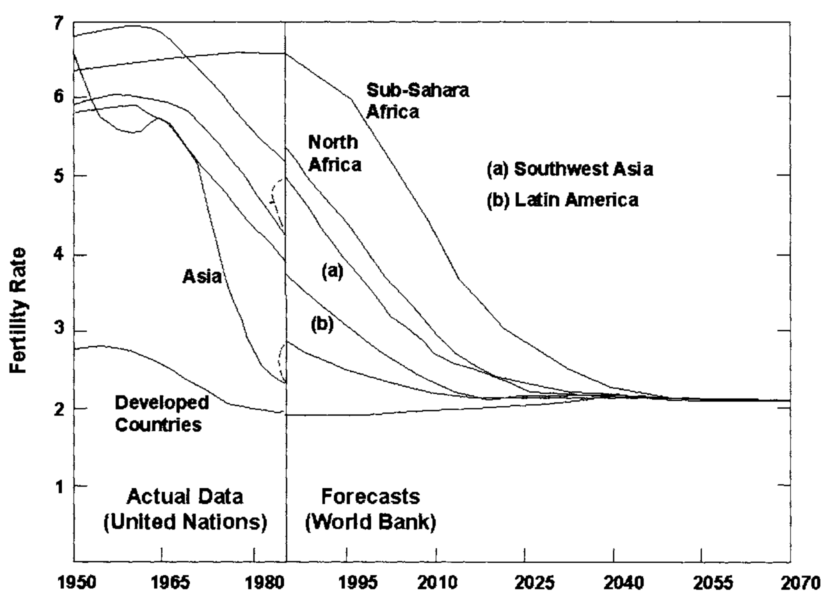
For two decades, major institutions such as the United Nations[58] and the World Bank[59] and individual demographers that make 50- to 150-year population forecasts have projected a world population of between eight billion and twelve billion that stabilizes sometime within the next century. Such agreement is qualified by the fact that almost all the forecasters use similar methods and assumptions.[60]

The common and key assumption for long-term forecasts is the completion of the demographic transition, specifically, that at some future date all couples within a country will reduce their births to a level at which they just reproduce themselves and will maintain that level over the next century (see *Figure* 6). The dates for when this should happen vary by the forecasters' assessment of the rapidity of the transition. According to a 1990 forecast, for example, it will take place in China by the year 2000, India by 2005, and Nigeria, much later, by 2035. Attaining this level of just reproducing the parents, however, does not mean that the population is stabilized, because the momentum of having a large population of young people just entering their reproductive life pushes up the growth for a long time. Thus, population growth would not diminish to negligible levels until 2075 in China, 2100 in India, and well into the twenty-second century in African nations.

The somewhat arbitrary choice of these dates matters, as do the assumptions about how quickly the death rate declines, and demographers therefore prefer to show low, medium, or high variants of their projections. The current variants of the major projections forecast a medium projection of ten to eleven billion and a low-high range between eight billion and fifteen billion for the end of the next century (see *Figure* 7). Even this broad range may be too narrow.[61] Demographers who have attempted to handicap the accuracy of UN forecasts for individual countries made an estimate of the average errors made by their UN brethren. Using these estimates they would even set wider limits, arguing that there is a two to one chance that in the year 2100, global population will fall somewhere between five billion and twenty billion people.[62]

These ranges assume that errors are equally possible in both directions, but the renewed concern for population is directed

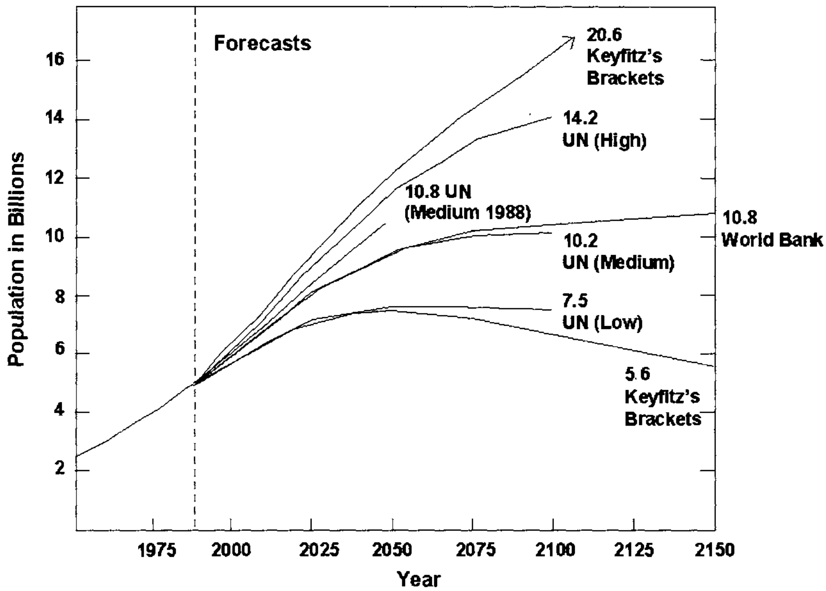
Figure 6. Projected Fertility Rates.



Note: Different methods explain the present discrepancies in the rates reported by the United Nations and the World Bank.

Source: Ronald Lee, "Long-Run Global Population Forecasts: A Critical Appraisal," in Kingsley Davis and Mikhail S. Bernstam, eds., *Resources, Environment and Population: Present Knowledge, Future Options* (New York: Oxford University Press, 1991), 58.

Figure 7. World Population Projections.



Source: Ronald Lee, "Long-Run Global Population Forecasts: A Critical Appraisal," in Kingsley Davis and Mikhail S. Bernstam, eds., *Resources, Environment and Population: Present Knowledge, Future Options* (New York: Oxford University Press, 1991), 59.

toward the upper end. Upward rather than downward creep is suggested by the apparent slowing of the decline in birthrates mentioned above. There are unknowns on the mortality end as well, although simulations of the impact of AIDS, for example, find that despite a death toll in many millions, AIDS has only a small effect on global projections involving billions.[63]

Even a doubling of the population could be too much if future consumers use and discard at the levels of Americans, rather than of Africans, today. One study extrapolating "current trends" found that a doubling of population requires a quadrupling of agriculture, a sextupling of energy, and an octupling of the economy if varied and nutritious diets, industrial products, and regular jobs are to be within reach of most of the ten billion people.[64]

Many find this 2–4–6–8 scenario unbelievable and unsustainable because of the extraordinary increases in production and consumption required by "just" the doubling of the population. Such increases could hardly be accommodated by current technology and practice in a human environment that already has seen substantial transformation of its atmosphere, soils, groundwater, and biota. If environmental catastrophe is to be postponed in such a warmer and more crowded world, it can be done only by maintaining great inequities in human welfare or by achieving different trajectories for technology and development.

As we contemplate what those different trajectories for technology and development might be, we can gauge the outlook through our temporal frames. We appear to be about halfway in numbers into the third great population surge, and the good news from the ages is thus that some relief may lie ahead, albeit in a century or so. Twentieth-century population and consumption growth is totally unprecedented in human history, and the bad news from the millennia is that great civilizations failed to maintain much smaller rates of growth in the past. We also have no news, especially from the centuries: our science can observe but not readily explain past and existing interactions of population, technology, and resources. But, like Malthus, we have theories. To address these interactions; to move beyond theories to practices; to assist in the passage through the Great Climacteric of the next decades—these challenges provide an extraordinary and fulfilling charter for studies of the human environment.

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