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Limits on and Consequences of Human Population Growth

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Abstract

This article reviews some theories and predictions about population, then suggests some simplified mathematical models that demonstrate that fertility rates, rather than longevity or the timing of parenthood, drive population growth. These models show why a total fertility rate close to the replacement value of 2 children per couple would minimize the burden on the tax-paying, child-raising generation. The paper goes on to discuss the dangers of a Malthusian catastrophe.

The Population Bomb (1968), which predicted that mass famine, war, disease, or a combination thereof would occur in the 1970s and 1980s, became a best-seller when I was a college student. Although such a Malthusian catastrophe has not materialized on the grand scale that Paul Ehrlich [1932–] envisioned, his concerns about human population growth are still at the center of many of the problems facing our world today.

A new generation of college students has replaced my generation, while I have moved to the front of the classroom. Although I'm just an English teacher, there is inevitably a content component to what I teach. You can't really teach language or even use it in a complete vacuum. Language classroom content may provide a valuable bonus to new vocabulary, grammar, and communication practice. While teaching a language, instructors can also provide important facts, useful academic skills, and stimulation for the student's imagination with opportunities to think deeply and produce original ideas (Table 1).

	declarative knowledge	ability to think	procedural knowledge
language	Vocabulary	Communication	Grammar
content	Important facts	Imagination and original ideas	Useful skills

Table 1 Educational components at language and content levels.

With this in mind, I would like to explore human population growth and the danger it poses to human civilization. The classical formulation in this field came from An Essay on the Principle of Population ... (1798) by T. Robert Malthus [1766–1834] in response to the utopian visions of the future that were published by William Godwin [1756–1836] and Marquis de Condorcet [1743–1794]. His more pessimistic theory holds that the geometric progression of population (driven by "passion between the sexes") will with mathematical certainty outstrip the arithmetic progression of food production and concludes that the inevitable result is a world of misery and vice, if not perpetual then at least cyclic. Like the subsistence theory of wages it predicts a low quality of life.

Parameters of Population Growth

World population has been increasing faster and faster. Two thousand years ago there were only 300 million people on our planet (Wales, 2006a). It took 1750 years for the population to reach 791 million. Only 100 years later the population had increased by 60% to reach 1,262 million. In the next hundred years it doubled, becoming 2,519 million. Then it took only 50 years to increase by 141% to 6,071 million. The present world population of more than 6.5 billion is expected to reach 8.9 billion by 2050.

year	population in thousands
0000	300,000
+1750	+164%
1750	791,000
+100	+60%
1850	1,262,000
+100	+100%
1950	2,518,629
+50	+141%
2000	6,070,581

Table 2

There are three basic parameters that control population growth: (a) fertility rate, (b) survival rates, and (c) the length of the interval between generations. Let's consider a mathematical model of population in which there are only three generations. We can think of them as (1) children, (2) parents, or (3) grandparents. In our simplified model after a fixed interval—a generation of 25 years, for example—everyone moves up one generation. All the grandparents die and a new generation of children is born. That is to say that the survival rates for children and parents are 100%, but for grandparents is 0%. The life span is 75 years. With two of the parameters set, we can look at the effects of the third—fertility rate.

If each pair of parents has two children, then the population will be stable. The number of children will be the same as the number of parents and of grandparents, let's say 100 (million). Then the total population would always remain 100 children+100 parents+100 grandparents=300 (like it was 2,000 years ago). There would be two children in each family of four (or six, if one set of grandparents lives with them). This 2-Child Population Model produces a stable population. Now let's take a look what happens when the fertility rate rises to four children per couple. After 25 years there will be an increase of 100 children (total population 400). A generation later there will be 400 children and 200 parents (total population 700). From then on the

generation	0	1	2	3	4	5	6	7	…
children	1	2	4	8	16	32	64	128	…
parents	1	1	2	4	8	16	32	64	…
garandparents	1	1	1	2	4	8	16	32	…
total	3	4	7	14	28	56	112	224	…

Table 3 The 4-Child Population Model [1=100 million].

population will double every generation. The population will rise so quickly that the increase can be described as an explosion. Starting with a population the size of America's (twice the size of Japan's) we get close to the world population after only six generations (about 150 years). Furthermore, the population is still continuing to double every 25 years. Fertility rates are what cause populations to explode in a geometrical progression.

Next let's consider the effects of the two other parameters. In the long run each indivitual's survival rate is 0%. Everyone dies; no one "gets out" alive. In our 3-Generation Population Model there are three survival rates, one for each transition: child to parent (C-P), parent to grandparent (P-G), and grandparent to great grandparent (G-GG). Survival rates determine life span. Because we are assuming survival rates of 100%, 100%, and 0%, the life span is three full generations or 75 years. If the G-GG survival rate rises above 0 for any reason—economic prosperity and medical advances, for example, we add a new generation. If rate goes to 20%, then life span increases by that percent of a generation.

20%×25 years=5 years.

That will cause the stable 2-Child Model to experience a one-time increase of 20 great grandparents and then stabilize at this new equilibrium. The exploding 4-Child Model will experience a one-time increase above its geometric increases and then settle back into its doubling mode for all four generations.

If the C-P survival rate falls below 100% the major effect on population will be the same as a corresponding drop in the fertility rate, as if they had never been born. Although a lower P-G survival rate in our simple model would have only a minor effect on population, similar to that of the G-GG survival rate, in the real world the death of a parent can negatively affect a child's chances of survival.

Increasing the length of a generation, our third and final parameter, will leave the characteristics of population growth unchanged except for the time scale. The population in our 2-Child Population Model remains stable and at the same level, but with an increased life span of 90 years, rather than 75. The population explosion of our 4-Child Population Model will still explode—a little more slowly, but just as surely. The important point here is that fertility rates and the C-P survival rate are what drive a population explosion. Longevity and the length of a generation have only minor roles to play.

Parameters of Economic Growth

Malthus' concern at the turn of the 19th century was that agricultural production could not keep pace with an exploding population. In order to consider why that might be, we need to assign economic roles—the dual roles of consumer and producer—to the members of our population model. To keep the model simple let us postulate that everyone consumes the same fixed amount, so that consumption is directly proportional to population. Parents only, however, are assumed to be productive members of society—an agricultural society—so they produce food. From Table 3 (above) we can see what happens as a rise in fertility creates a population explosion. The portion of the population that is productive initially drops from 33.3% to 25%, then reaches an equilibrium at 28.6%. After that, both population and food production should expand at the same exponential rate allowing a fixed level of per capita consumption. Two basic economic forces, however, often cause efficiency to deviate from any such fixed level: the Law of Diminishing Returns and economies of scale.

The Law of Diminishing Returns predicts that efficiency will decrease as production increases. That is because the most efficient factors of production will be employed first. In an agricultural society the most productive land would be cultivated first. As population and the demand for food grows, less and less productive land comes under cultivation. Nutrients in the soil might also become depleted with continued cultivation causing further decreases in productivity. Eventually you might even run out of a fixed resource such as land. Thus per capita production would be expected to decline with a rise in population if not for the compensating increases in efficiency for large scale production.

Advances in agricultural technology, transportation, and communication coupled with mass production and economies of scale have allowed the more advanced and densely populated cultures to produce and distribute food more and more efficiently (Diamond, 1999). It all began with the domestication of plants and animals during the Neolithic Revolution. Hunter-gatherers discovered that they could get more food for less effort by farming than nature provided in fields and forests. As farm land and population increased surplus labor migrated to big cities where a money-based economy allowed division and specialization of labor in factories, which produced farming machinery, chemicals, and pesticides. Thus industrialization caused a second agricultural revolution. Family farms became large-scale agribusinesses. Advances in transportation and communication allowed mass marketing and distribution of mass produced agricultural products. It also allowed diffusion of technological advances, such as Norman Borlaug's high-yield strains of wheat and rice that came to be known as the Green Revolution [1943–1960s], bringing the world's supply of food per capita to at an all time high.

Limited Resources

During the last 200 years as the population went from 1 billion to 6 billion, the surface of the Earth has remained fixed at 510 million square kilometers with about 70 percent of that area under salt water. At the time Malthus was writing his theory, the excess population of the British Isles was still pouring into North America and Australia. Africa and the Americas were largely covered by forests teeming with wildlife, so that the concern was with the ability of society to produce food, shelter, clothing, and, later, industrial machinery that would further accelerate production and transport the supply of goods to wherever the demand was greatest. The focus of concern has now shifted from production and supply to the availability of a range of natural resources (see Table 4).

resources	production	supply
arable land	crops	food
animal habitats	animal populations	meat and fish
fossil fuels	energy	goods and services

Table 4 Scarcity of per capita (a) resources (b) production (c) supply.

Historically forests have been cleared to make way for farms and houses, and the "taming of the wilderness" was seen as a good thing—progress and economic growth. Now, however, deforestation is seen as a threat to our environment and a precursor to desertification. Dense populations crowded into urban centers are producing waste that pollutes air, water, and soil. The lack of foliage to absorb the sun's energy and convert carbon dioxide from the atmosphere into oxygen has raised temperatures and worries about climate change and a rising sea level as the polar ice caps melt away. Living space in the cities has been expanded through the technology of high-rise buildings, but the crowded conditions may well be contributing to stressful lifestyles that encourage outbreaks of violent behavior.

Humans are not the only creatures that suffer due to the lack of living space. Hunting, fishing, and the destruction of animal habitats is causing animal populations to plummet. On land and in the seas man is competing with the other animals for food. The animals are losing badly, causing extinctions at such an alarming rate that it ranks up there with other great extintion events of the past and is causing scientists to worry about a lack of biodiversity.

Technology has always come to our rescue in the past, starting with agriculture and animal domestication. Some people even argue that rather than struggling to keep up with the growing human population, technology is the engine that pushes our population ever higher. As we developed new forms of energy—steam, electricity, gasoline, and atomic energy—the complex systems of production, transportation, and communication upon which industrial societies rely have become, in turn, dependent upon these energy sources. How can we ever go back to the old way of doing things without going back to a much lower population with lower levels of consumption?

Using bell-shaped curves geophysicist Marion Hubbert successfully predicted in 1956 that U.S. oil production would reach a peak in 1970. Initially greeted with skepticism, his theory has since become a standard tool for the oil industry's own forecasts. Global oil production is expected to increase until about 2010, but at a rate slower than that of population growth. Thus, according to Olduvai theory, per capita energy production peaked at 11.15 barrels of oil equivalent (boe) per capita per year way back in 1979 and is destined to slide, catastrophically bringing industrial civilization (defined as 30% of peak production = 3.32 boe per capita per year) to an end (Wales et al., 2006b). Meanwhile the search continues for future sources of energy.

Stages of Population Growth

One of the consequences of Malthus' theory of population was to promote the idea of a national census to measure population dynamics. Many countries have adopted the practice of taking a census, usually at intervals of five or ten years. The accumulated data allowed Warren Thompson and F. W. Notestein to develop the Demographic Transition Model (DTM). By 1945 the model described four stages of economic development.

1—pre-industrial society with high, fluctuating birth and death rates
2—developing countries with lower death rates and expanding population
3—birth rates fall and population begins to level off
4—birth rates drop further causing population to stabilize or even decline

There has been a general decline in fertility in many parts of the world. In a few countries, like Russia, Ukraine, and Japan, sustained sub-replacement fertility has been severe enough to cause populations to decline (Wales et al., 2006c). In Japan, which has an incredibly high population density of 300 people per square kilometer, you might think that a decline in the population would be viewed with relief. After all, this country has three times the population density of China, a country that has instituted a One Child Policy to stem its own population growth. The subways in Japan are so crowded during the morning rush hour that cities, such as Tokyo and Nagoya, feel the need to have special women only cars. It is not only universities and other sectors of a depressed economy that cater to young people that are worried about the repercussions. Government tax offices are worried, too.

Let's examine three simple population models to see if these tax concerns might be justified. Remember that our models assume that all production comes from the parents. We can further postulate that (a) they raise their own children—their parental burden and (b) pay taxes to support the entire group of grandparents (all of whom are retired)—their tax burden. Observe the shifting burden as fertility drops from the 4-Child (expanding) Population Model to the 2-Child (stable) Population Model. In an expanding population each set of parents is supporting 5 people, four children and one grandparent, while in a stable population each set is supporting 4 people, two children and two grandparents. If, as we have previously assumed, everyone consumes at the same level, then the combined parental and tax burden is less. That's the good news, but if fertility drops below replacement levels to 1-child per couple the burden continues to shift from parental responsibilities to taxes. In the 1-Child (contracting) Population Model each couple supports one child and four grandparents. The burden returns to the level of five people per couple. In so doing, the burden shifts from a voluntary parental burden to an involuntary tax burden. The involuntary character of this burden might make it psychologically harder to accept. Unlike taxes, the responsibilities and burdens of parenthood can be avoided by not becoming parents in the first place. That, in fact, may well explain why the fertility rate is dropping in countries like Japan.

The United Nations has announced three possible projections for global population growth—none of them as radical as our 4-child and 1-child models, of course. Please keep in mind that because of child mortality in the real world, a total fertility rate of 2.2 is actually needed to maintain a stable population with 4 people being supported by each couple. Although the U.N.'s high projection of 2.35 children per couple represents a slowing of current birth rates and a lowered burden on the middle generation (parents) of 4.009 people per couple, exponential growth would continue to push population up with no end in sight. The U.N.'s medium projection of 1.85 allows the population to peak at 9 billion in the year 2075, while burdening each couple with 4.060 dependents. The low projection of 1.35 would have us reach the peak of 7.4 billion by 2050 with the burden increased to 4.487 dependents per couple. Cobb (2006) predicts an even steeper decline in birth rates with a peak of 7 billion in 2040. If he is right, this uncomfortably steep decline will undoubtedly create considerable stress.

The Struggle for Survival

Disease and death have always kept plant and animal populations in check (see Coutts, n.d.). It's all a part of the growing-aging process. Famine, war, and epidemics simply accelerate that very natural process. It's a matter of degree and timing. Ehrlich's predictions of catastrophe have all been realized in less dramatic form than he envisioned.

Conditions of hunger and malnutrition seem always to be present in developing countries, where populations have reached a saturation level for an agricultural way of life. Then natural or socio-political disturbances can trigger large-scale famine—as they did in Bangladesh in 1974, in Ethiopia in 1984 and 1985, and in North Korea from 1997 to 1999. Luckily famines have remained both regional and sporadic with death tolls contained to the order of one million. On a global scale there seems to be enough food for our most basic needs, though it is not distributed equally by any means.

Demand for a limited supply of scarce resources, goods, and services leads to such fierce competition within the human species that it frequently ignites violent behavior between individuals, groups, and governments. Urban centers with high-density populations seem to generate the lion's share of violent crime. At the international level large conventional wars have, to a large extent, been replaced by civil wars accompanied often by logistic support and occasionally by the intervention of major powers. Four million people perished in the Second Congo War from 1998 to 2004 and as many as 2 million in Afghanistan between 1979 when the Soviets intervened and 2001 before the American invasion. By comparison the more conventional Iran-Iraq War (1980–1988) produced about one million casualties. Fighting breaks out between religious and ethnic groups as often as it does between ideologies. This has led to massacres such as those that took place in September 1982 at Sabra and Shatila and genocide like that in Bosnia (1992–1995) and Rwanda in 1994, with death tolls in the hundreds of thousands. The development of weapons of mass destruction, their spread to unstable countries, and the export of suicide terrorism from the Middle East to other parts of the globe has greatly increased the chances of a man-made catastrophe.

While groups of Homo sapiens are locked in mortal combat with members of their own species, all of mankind is engaged in interspecies competition at both the micro and macro levels. Microscopic organisms and viruses can take advantage of high human population density and mobility. The Spanish flu epidemic of 1918–1920 killed at least three, perhaps six, times as many people as did the combat of World War I 1914–1918. Almost 100 years later a similar strain of avian flu threatens a larger, denser world population. Attempts to eradicate our micro enemies, unfortunately, have only been successful against one virus. Now with only a small portion of young people vaccinated against smallpox, the worry is that a man-made virus could become a devastatingly powerful biological weapon. For a while tuberculosis seemed to be retreating, then in the 1990s it made a comeback, causing the World Health Organization to declare a global health emergency. Meanwhile AIDS continues to make steady progress. All the while Richard Dawkins' Blind Watchmaker keeps churning out new challenges to our antibiotic arsenal—new drug resistant strains and new diseases such as SARS and Ebola.

On a macroscopic scale, humans have been perhaps too successful at dominating other species, sometimes to the point of extinction. Human activity has tended to destroy any species that we cannot domesticate. Wildlife is disappearing so fast that it has already been named the Holocene extinction event. Not only are we ruining the habitats of countless animals and plants, we are destroying our own habitat with contaminated soil and polluted water. Chemicals we pour into the atmosphere are destroying the protective ozone layer and raising temperatures to a point that threatens our climates (see Gitlin, 2006). Clearly we need to reduce our consumption of natural resources and disposal of waste. In order to do that, we need to limit our population.

Conclusions

Major catastrophes measuring in the tens of millions of deaths have already occurred. Famine in China claimed 30 million lives between 1958 and 1960; World War II claimed 62 million; and the Spanish flu cost anywhere from 50 to 100 million lives worldwide. Yet populations have continued to climb. To my knowledge the only modern country to experience a prolonged drop in population, when its potato crops failed in 1845, is Ireland. One hundred and sixty years later it still has only about one half of the population it used to have. One million people starved; many more escaped to British colonies.

Today, with no open frontiers on the horizon, population pressures have become tangible throughout the world. Birth rates in the most developed countries have started to drop. This is a healthy and wise response. Total fertility rates slightly below the replacement level of 2.2 per couple are the key to getting the global population to level off and begin to drop sometime this century. Potential catastrophes are plentiful. Undoubtedly some will materialize, hopefully in a mitigated form that will not send human population into a free fall—a Malthusian catastrophe. It is pretty clear that the world is due for a Malthusian adjustment. Perhaps we can control the descent—slow it down in order to minimize the stress for human civilization and arrive at a lower population that will allow a high quality of life for all.

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