Population, Food, and Knowledge

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Population, Food, and Knowledge

By D. GALE JOHNSON*

People today have more adequate nutrition than ever before and acquire that nutrition at the lowest cost in all human history, while the world has more people than ever before—not by a little but by a lot. This is an achievement that many have argued could not be realized. Throughout history there have been those who believed that food shortages and famine were the fate of humanity and that the world's population was restricted not by human decisions on fertility but by limitations imposed by nature. Unfortunately for nearly all of human history and for the vast majority of the world's people, this pessimism was justified. In the last two centuries, and especially in the twentieth century, all has changed to a remarkable degree. The twentieth century can be remembered as the century in which hunger could have been eliminated and, to a significant extent, has been.

I. Food and Population Growth

Thomas Robert Malthus, publishing the first edition of his famous *An Essay on the Principles of Population* in 1798, is usually credited with the pessimistic view that population had a tendency to outrun the available food supply and was held in check by vice and misery—war, disease, or starvation—but he was not the originator of the idea. At least two millennia earlier it was written in the Bible: "When goods increase, those who eat them increase." (Ecclesiastes 5.)

Quintus Septimus Florence Tertillianus wrote:

> Indeed it is certain, it is clear to see, that the earth itself is currently more cultivated and developed than in earlier times. Now all places are accessible, all are documented, all are full of business. The most charming farms obliterate empty places, ploughed fields vanquish forests, herds drive out wild beasts, sandy places are planted with crops, stones are fixed, swamps drained, and there are such great cities where formerly hardly a hut ... everywhere there is a dwelling, everywhere a multitude, everywhere a government, everywhere there is life. The greatest evidence of the large number of people: we are burdensome to the world, the resources are scarcely adequate to us; and our needs straiten us and complaints are everywhere while already nature does not sustain us. Truly, pestilence and hunger and war and flood must be consider as a remedy for nations, like a pruning back of the human race becoming excessive in numbers. (Bart K. Holland, 1993 pp. 328–29.)

This was written about 200 A.D. when the world's population was approximately 200 million. Note that the quotation includes nearly all the modern complaints about the effects of excessive population on the environment—deforestation, loss of biological diversity, farming unsuitable land, drainage of the natural refuges for wildlife—as well as the massing of people in cities.

While Malthus was neither the first, nor the last, to claim population growth carried with it the seeds of disaster for humanity, he may have been the first to significantly modify his view that population growth would inevitably press against the food supply. Five years after the gloomy first edition, in the second edition of *An Essay on the Principles of Population* he significantly modified his major conclusion. After noting the recent growth of European population, he wrote:

> ... fewer famines and fewer diseases arising from want have prevailed in the last century than in those that preceded it. On the whole, therefore, though our future prospects respecting the mitigation of the

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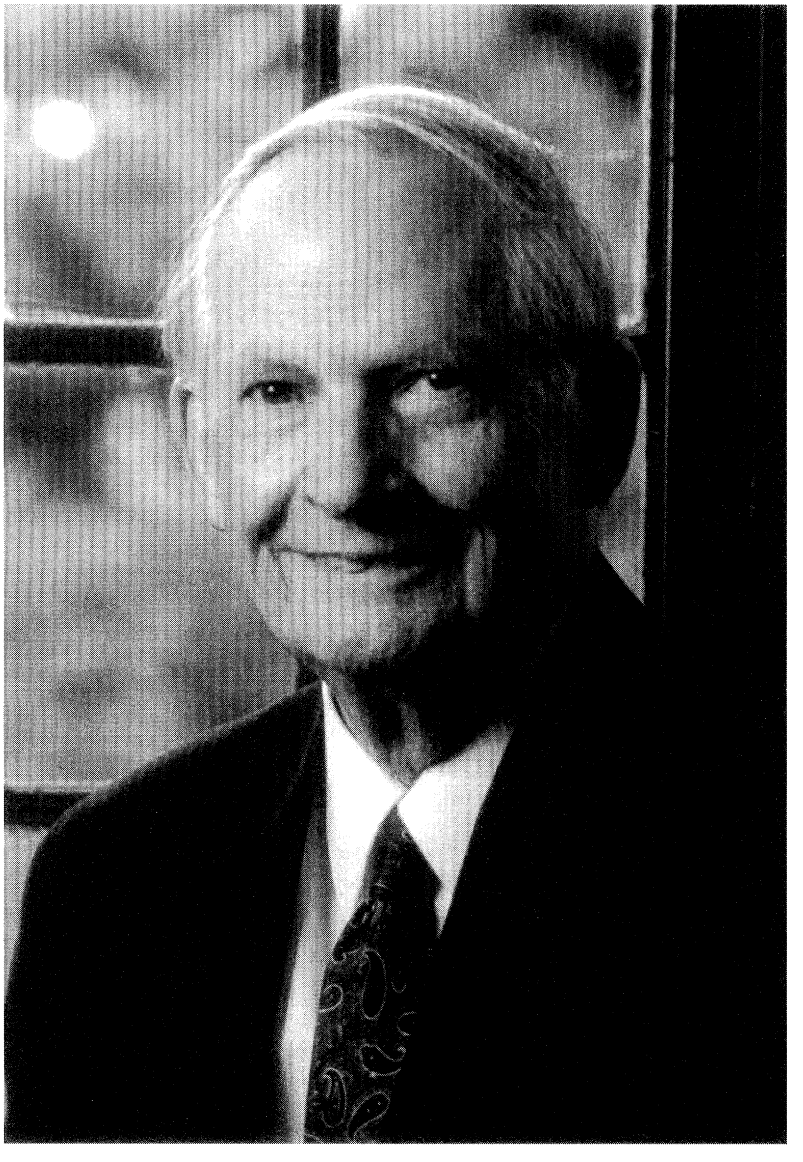

D. Hale Jamison

> evils arising from the principle of population may not be so bright as we could wish, yet they are far from entirely disheartening and by no means preclude gradual and progressive improvement in human society which, before the late wild speculations on the subject, was the object of rational expectations. (Malthus, 1992 pp. 330–31.)

Unfortunately, the Malthus of the first edition provided a model of population growth that accurately depicted the experience of nearly all of human history and was generally valid up to the time he wrote. But he was also correct in his view that during the century following the publication of the essay that there would be gradual improvement in the well-being of people in the part of the world where he lived, namely Europe. However, the progress was neither uniform nor without interruption, as witness the Irish famine of the 1840's and other famines and food shortages that occurred in several European countries during the nineteenth century.

In the second edition he recognized a third factor that affected population growth in addition to vice and misery—namely, the desire for self-improvement. In other words, families were willing and capable of influencing the number of children by changing the age of marriage, for example.

What made it possible for the world to escape from what could be called the Malthusian trap? The answer is simple: the creation of knowledge.[1] While there had been improvements in agriculture for many millennia through knowledge gained from practical experience—learning by doing—there was an explosion of knowledge over the past two centuries that made possible an unparalleled increase in per capita well-being, not just in terms of food but in all aspects of life. Fundamentally, new technologies have been developed at a rate unprecedented by historical standards.

Consider the following (Angus Maddison, 1995):

1. The increase in the world's population in the decade of the 1980's of 844 million was nearly as large as the world's total population in 1800 of 900 million.
2. During the decade of the 1980's the increase in the world's gross domestic product per capita equaled the estimated per capita gross domestic product in 1820 (Maddison, 1995 p. 228).
   Measured in 1990$, in the 1980's the per capita GDP increased by $661; the per capita figure for 1820 was $651.
3. The physical world—the land, the water, the air, the sun—was basically the same in the 1980's as it was in 1820 or 1020 or 10,000 years ago. Some might argue that the physical world was less valuable than in the past.

The magnitude of the increase in the world's output since 1820 is much greater than is directly implied by the comparability of the increase in GDP during the 1980's and in all history up to 1820. The increase in real world output during the 1980's was more than 10 times the output in 1820 and the world output in 1990 was 40 times that of 1820. How could these enormous changes have occurred? They occurred because we have found ways to offset the limitations that natural resources imposed on the world's output in times past as well as improving greatly the amount and productivity of human capital. We have not found how to repeal the principle of diminishing marginal returns. But we have found low cost and abundant substitutes for natural resources important in the production process.

As I will show later, the improvement in well-being of the world's population goes far beyond the enormous increase in the value of the world's output. The improvements are evident in fewer famines, increased caloric intakes, reduced child and infant mortality, increased life expectancy, great reductions in time worked, and greatly increased percentage of the population that is literate.

[1] I have an enormous intellectual debt to many people for the ideas that I have tried to put together in this paper. Rather than interrupt the flow of the text with the numerous citations that could be made, I wish to specify the individuals and publications that have had the greatest influence: Theodore W. Schultz (1964), Simon Kuznets (1966, 1979), Paul M. Romer (1986, 1990), Paul Bairoch (1988), Zvi Griliches (1988, 1998), Robert E. Lucas, Jr. (1988, 1993), Gary S. Becker (1991), Malthus (1992), and Robert W. Fogel (1996, 1999). I have not provided a full list of papers that have influenced my thinking but only the one or two that had the most influence. My debts to many others for data are indicated at the appropriate points.

This lecture proceeds in the following way. I show that for most of human history, life was both short and difficult for the vast majority of the world's people, that food supply was a major factor affecting population size, and that consumption—nonfood as well as food—was very limited. I shall then turn to the question of how the developed world escaped from the Malthusian trap during the nineteenth century and how the developing world did so more than a century later.

I emphasize three major factors that I consider responsible for the remarkable period of economic growth that has occurred over the past two or three centuries that permitted breaking free from the limits imposed by the food supply. The first factor is the significant advances in agricultural productivity in the eighteenth and nineteenth centuries. The increase in agricultural productivity made possible the development of cities as the major focus of further economic development and growth. The second factor is the enormous increase in knowledge over the past two centuries made possible by increasing population and rising real per capita incomes resulting from the economic growth from the mid-eighteenth century. The increase in real incomes permitted the allocation of substantial resources to the creation of knowledge. This reallocation was associated with the rapid development of two institutions—universities and research institutes. The third factor, contrary to what is often assumed, is that the response of families to the removal of restraints on their well-being imposed by limited food supplies was not significantly increased fertility; population growth resulted primarily from mortality declines. Population growth was not limited by the supply of food but by the decisions of families.

The three reasons do not fully explain why population growth did not spoil everything for the developed world in the nineteenth century and for the developing world more recently. One reason the growth of food output in the nineteenth century may not have been overwhelmed by population growth was that knowledge and technology required for the rapid reduction of mortality did not become generally available until near the end of the nineteenth century and, further, the rapid increase in the population of cities limited the decline in mortality. The decline in mortality in the developing world in the twentieth century was far more rapid and resulted in a much higher rate of population growth than the experience of the nineteenth century even though fertility declined significantly.

II. Agriculture and Food Before the Nineteenth Century

Agriculture is a relatively recent invention—the transformation from hunting and gathering to planting and growing crops and domesticating animals probably occurred about 10 millennia ago. At that time the world's population was about 4 million and a large fraction of all resources were devoted to obtaining food, and a very poor lot it was.

As of 1800 it is estimated that 75 to 80 percent of the working population in the developed world was engaged in agriculture (Bairoch, 1988 p. 287). In the rest of the world, with nearly 80 percent of the world's population, the percentage of workers engaged in agriculture was certainly higher—of the order of 85 to 90 percent. In 1891, 90 percent of the population of India was rural (Adna Ferrin Weber, 1899 p. 124) and as late as 1949, 89 percent of China's population was rural.[2] Unfortunately we do not have evidence that permits us to directly determine the amount of food available in ancient times. But if life expectancy in Roman times were 25 years (Donald J. Bogue, 1969 p. 566), it is highly probable that the available food per capita was very limited. Fogel has estimated the

[2] To say that a high percentage of the working population was engaged in agriculture does not mean that this was the share of labor time devoted to the production of agricultural products. Prior to the nineteenth century, farm families were largely self-sufficient and had to devote a significant percentage of their labor to provide for their housing, to collect fuel, and to make their own clothing, bedding and furniture, and most of the simple tools and equipment that they used on the farm and in the house. In temperate climatic zones much of this work may have occurred during the colder periods when little or no farm work could be done, other than caring for animals. The percentage of the labor force engaged in agriculture is a rough inverse indicator of the percentage of their food production that they could sell to nonfarmers. If 80 percent of the population were engaged in agriculture, they could sell or trade approximately a fifth of the food they produced.

daily caloric supplies at the beginning of the eighteenth century of 2,095 for Great Britain and 1,657 for France (Fogel, 1996 p. 10). Life expectancy for England in 1725 is estimated to be 32 years and in France in 1750, 26 years. Over the next century per capita calories increased by approximately 10 percent—to 2,237 in Great Britain and to 1,846 in France and by 1800 life expectancy in England was 36 years and in France 32 years (Fogel, 1996 p. 2). Obviously other factors had a role in the increase in life expectancy, but it is unlikely that these increases and those that followed would have occurred in the absence of improved nutritional intake.

A life expectancy of between 25 and 30 years was probably the fate of most of humanity throughout recorded history until about 1650 (Bogue, 1969 p. 566). It was not until the seventeenth century that there is evidence that life expectancy increased significantly beyond what it was in Roman or earlier times. As noted, England and France, two of the wealthiest nations of the world, had life expectancies at the beginning of the eighteenth century that were not much above what had prevailed throughout human history.

It is probable that the per capita calorie supplies for the world prior to the seventeenth century were in the range found in England and France at the beginning of the eighteenth century—perhaps from 1,650 to less than 2,000. These are in the range of calorie intakes in many developing countries in 1934–1938, the earliest date for which we have estimates for several countries. Calorie intakes in India, the Philippines, Peru, Colombia, and Mexico were in the range of 1,800 to 2,000 calories (M. K. Bennett, 1976 p. 199). By 1934–1938 these countries had significant population growth rates and at earlier times consumption was probably rather less.

Important evidence that the productivity of agricultural resources in Europe remained relatively constant and low was that in Europe, excluding Russia, there was almost no change in the percentage of the total urban population between 1300 and 1800. Bairoch (1988 pp. 177, 216) estimates that in 1300 the urban population of Europe was 10.4 percent of the total; five centuries later in 1800 it was only 12.1 percent and most of this increase occurred in England in the eighteenth century.[3] The nineteenth century saw a major increase in urbanization; by the end of the nineteenth century the urban population was 37.9 percent of Europe's population, Russia excluded. The urban population increased almost five times in the nineteenth century after little more than doubling in the previous five centuries (Bairoch, 1988 pp. 177, 216). The development of cities as a significant share of the total population became possible only after farmers increased production relative to their own consumption.

Further evidence that per capita output of agriculture increased very little throughout history was the slow growth of world population until nearly the beginning of the nineteenth century. During the first millennium of the current era, the annual rate of growth was 0.04 percent, a doubling time of 1700 years. In the 700 years ending in 1700, the rate of population growth was 0.12 percent, a doubling time of about 580 years. The rate of population growth did increase in the eighteenth century—to 0.41 percent annually. But even at that rate it would take 179 years to double.

Europe's population during the eighteenth century increased from 102 million to 154 million and this increase was made possible by a significant increase in food production occurred. However, except in England, there was no increase in urbanization so it is reasonable to infer that in the rest of Europe the growth of food production increased at approximately the same rate as population during the eighteenth century.

III. Agriculture and the Industrial Revolution

What was agriculture's contribution to the Industrial Revolution? The Industrial Revolution is generally considered to have started

[3] England was the exception; it had a significant increase in urbanization during the eighteenth century. Bairoch (1988 p. 215) estimates that the percentage of the population that was urban in 1700 was 13–16, in 1750, 17–19, and in 1800, 22–24. For Europe, excluding England, there was no increase in urbanization as a percentage of the total population in the eighteenth century. England was also an important exception because it had a significant growth rate of population in the last half of the eighteenth century of 0.82 percent annually compared to 0.5 percent for Europe (excluding Russia).

about 1750 in England and up to a century later in the rest of Europe. As I have noted, the share of cities in Europe's population had remained nearly constant for the previous five centuries, and that this meant that the available food supply had not increased significantly faster than population and, equally important, that the productivity of labor in agriculture also had not increased enough to permit labor to transfer out of agriculture and migrate to cities. The midpoint of the eighteenth century marks a striking dividing point in the demographic and agricultural history of England. In the century up to 1750 England's population was static. It actually declined in some periods and increased at an annual rate of only 0.1 percent or by 10 percent in the entire century (E. A. Wrigley and R. S. Schofield, 1981 pp. 528–29). Life expectancy may have actually declined. But between 1751 and 1801 its population grew at an annual rate of 0.81 percent and the total increased by 50 percent. In the next half century the population nearly doubled. Nearly all of the increase in the United Kingdom's population in the nineteenth century was urban (Bairoch, 1988 p. 290).[4]

What increased productivity in agriculture so strikingly after 1750? Exact causes are unknown, but many changes were involved, including the spread of two high-yielding crops from the Americas—corn (maize) and potatoes, the enclosure movement, the elimination of fallow, improved drainage, and increased availability of animal manure made possible by the cultivation of turnips as feed for cattle (David S. Landes, 1969 p. 76). There was a major increase in England and the Netherlands in the grain-to-seed ratio to more than ten in 1750–1820 compared to seven in the two centuries prior to 1700 (B. H. Slicher van Bath, 1963).[5] Such a large increase in yield was almost certainly associated with a significant increase in labor productivity. While urbanization increased very little in England during the last half of the eighteenth century, there was a significant expansion of industrial activity in rural areas, especially in the production of textiles.

Significant increases in per capita food production and in labor productivity in agriculture were necessary conditions for the Industrial Revolution which was associated with, and may well have been advanced by, rapid population growth. The increase in food production was necessary to sustain the rapid population growth; the growth in agricultural labor productivity was required to permit a reduction in the share of labor devoted to farming and to permit the transfer of labor to the cities. I do not argue that the improvements in food supply and labor productivity were sufficient conditions for the Industrial Revolution. It is quite probable that the agricultural and industrial revolutions had the same sources and each was affected by developments in the other.

IV. The Mechanical Revolution

The improvements in labor productivity in agriculture occurring in the eighteenth century and the early years of the nineteenth century were insignificant compared to the changes that occurred in the rest of the century. Throughout history for most of the world's population the

[4] During the nineteenth century the United Kingdom was transformed from a rural to an urban economy. In 1800 it was 19.4 percent urban and in 1900, 67.6 urban. The population increased from 16 million in 1800 to 41 million in 1900, an increase of 25 million, while the urban population increased by 24 million. Continental Europe was only 32.9 percent urban in 1900 (Bairoch, 1988 p. 290).

[5] It is not clear whether the increase in food production in Western Europe in the eighteenth century after 1725 was due primarily to productivity improvements or to a lengthy period of good weather. Ronald Maxwell Hartwell (1971 p. 283) speculates that good weather might have been a significant factor:

> An important, neglected and completely exogenous factor (perhaps the only one that is really exogenous), affecting eighteenth-century growth was the beginning after 1730 of more than two centuries of "good" weather (relative to the "bad" weather of the previous more than two centuries). The coincidence in time of the beginnings of the industrial revolution and a long period of good weather suggests the possibility of a theory of weather-induced growth: better weather enabling an increase in food supplies, increasing real incomes, and also an increasing population.

The weather, through its effects on food production, could have been a factor in the slow growth of England's population of 0.13 percent annually from 1621 to 1721 compared to the much more rapid annual growth rate of 0.77 percent in the following century (Wrigley and Schofield, 1981 pp. 528–29).

major source of calories has been grain—of the order of 75 to 80 percent (Bennett, 1976 p. 206). Until the early nineteenth century the serious bottleneck in the production of grain was harvesting. The plow was introduced several millennia before, and it saved labor, but at a time of the year when labor was not scarce. Plowing could be done over an extended period of time, but harvesting in most areas had to be done in a brief period to prevent the crop being harmed or destroyed by wind, rain, or frost.

At the beginning of the nineteenth century grain was harvested by the same methods as in the fourteenth century and probably much earlier—the sickle, the scythe, and the cradle. The invention and introduction of the reaper in America in the second quarter of the nineteenth century changed all that. The reaper was soon followed by the binder, which was a reaper with an attachment that brought the grain straw together in a bundle and tied it with twine. The binder was complemented by the thresher that saved a great deal of labor, though at a time less critical than the savings made possible by the reaper and binder. In turn the binder and thresher were largely replaced by the combine, but not until well into the twentieth century.

Many other machines and tools were part of the mechanical revolution. Very important was harnessing the internal combustion engine to create the tractor. The labor savings of the mechanical revolution were enormous. It is estimated that the direct labor input used to produce a ton of grain in the United States declined by 70 percent in the nineteenth century (Martin R. Cooper et al., 1947). Consequently in the developed countries after the mid-nineteenth century the transfer of labor from agriculture to nonagricultural pursuits was more likely limited by the rate of growth of nonagricultural employment than by the labor requirements of agriculture.

V. Land Was Not the Scarce Resource

While today many give emphasis to the limited supply of land of good quality as a major impediment to further increases in food production, throughout nearly all of human history land has not been an important factor limiting production. It had to have been something else when the world's population was 500 million, as it was in the sixteenth century, or perhaps even when the population first reached one billion, early in the nineteenth century. Given the state of knowledge that existed until quite recently, the primary limiting factor was labor. Labor limited the amount of food that could be produced by a family and, as noted, for much of human history, farm families were barely able to produce enough for their own consumption with little surplus for trade with others. Until quite recently this surplus was hardly more than a quarter or a fifth of what they produced. A good indicator that land was not the limiting factor is that until the beginning of the nineteenth century yields were calculated per unit of seed, not per unit of land (Slicher van Bath, 1963).

Ester Boserup (1965) makes a convincing case that labor and not land was the limiting factor in agricultural output until quite recently. She showed how farmers adapted to increasing population by modifying the ways that land was utilized, shifting from slash and burn and long fallow to shorter periods of fallow and in Western Europe eliminating fallow entirely. They found ways other than fallow to maintain the fertility of the soil—the use of manure and legumes, for example. These changes were the result of new knowledge, knowledge largely derived from experience of the farmers themselves and were a response to the growing population and the need to expand food production.

VI. The Increased Role of Knowledge

As noted, the enormous increase in the world's output over the past two centuries has been due in large part to the advancement of knowledge combined with the increase in human resources, both in number and capabilities, and savings translated into physical capital. We do not have more natural resources than existed in the distant past, yet output has increased many fold. What is the source of the increased knowledge? Two factors have been important—one is simply the growth of population and the other is that rising real per capita incomes have made it possible for specialization in the production of knowledge and for devoting a significant share of our resources to that effort.

Michael Kremer (1993) makes a convincing case for the conclusion that a larger population

leads to greater creation of knowledge. First, the larger the population, the greater the benefit from a given improvement in productivity resulting from new knowledge. Second, with a larger population, there are more individuals capable of making a significant discovery or adding to knowledge. It is not that today we are smarter or more intelligent than populations a century ago, two centuries ago, or a millennium ago. Presumably the distribution of talents or intelligence is the same today as at any past time. But there are many, many more of us and if the distribution of talents has not changed, there are many more individuals capable of advancing knowledge.

But it is not only that there are more of us available to add to the world's knowledge, but with the improvements in agricultural productivity, the expansion of the cities, and the very large increases in real per capita incomes that have occurred over the past two centuries, institutions have been created specifically to advance and transmit knowledge. I refer to universities and research institutes, including both public and private ones. It was not that prior to the nineteenth and twentieth centuries that there were no individuals who had the intelligence, time, curiosity, and energy for the creation of knowledge. But their numbers were limited. Our lives, however, are greatly influenced by those who developed the reaper and the binder, the internal combustion engine, the steam engine, the railroad, electricity, the telephone, and by those who discovered the small pox vaccine and the germ theory of disease. But by the beginning of the twentieth century their effects on the lives of individuals were limited compared to the effects of the recent increases in knowledge and their applications.

When as many as 80 to 85 percent of the world's labor force was engaged in farming, a small percentage of a much smaller world population had the time and resources to devote to producing nonfood products, such as clothing, tools, roads, and housing, let alone acquiring new knowledge and technology. In 1990 in the developed world no more than 10 percent of its labor force was engaged in agriculture and in the developing world approximately 60 percent (World Bank, 1997 p. 220). Not only are there about seven times as many people as there were in 1800, but a significant percentage of this much larger population specializes in the creation of knowledge compared to the very small number who could do so just two centuries ago. The modern university, with many faculty devoting their time to research in science and graduate education, is a very recent creation—such institutions hardly existed before the middle of the nineteenth century. German universities dominated the world's graduate education in the nineteenth century. Yet as of 1900 in all the German universities there were only 38,000 students and 1,830 faculty (Friedrich Paulsen, 1908 p. 193); these are totals for all colleges and universities, not just those engaged in graduate education.

In 1869–1970, only a single Ph.D. was awarded in the United States (U.S. Bureau of the Census, Department of Commerce, 1960). The development of colleges and universities after 1869–1970 was quite remarkable. In that year there were 563 colleges and universities with a total faculty of 5,553 and 52,000 students. The contribution to new knowledge had to be limited; there were approximately ten faculty members per institution, including, I assume, the president who probably spent much of the available time trying to find enough financial resources to keep the institution open. Sixty years later, for example, there were 82,000 faculty, 1.1 million students, and 2,299 doctorates awarded. Further rapid expansion of higher education came after World War II and by 1994/1995 there were an estimated 915,000 faculty, 14.3 million students, and 43,000 doctorates awarded (Thomas D. Snyder, 1993).

In part, as a result of World War II, the governmental support of research in universities and federal research laboratories was greatly expanded and many private research institutes were created and developed. Prior to World War II federal support of research was largely concentrated in agriculture and the military.[6]

[6] One of the great achievements of the presidency of Abraham Lincoln was the creation of a land grant college in each state. These colleges were to specialize in agriculture and engineering and to provide education that emphasized the practical as well as the theoretical. Approximately two decades later the agricultural experiment stations were established. The establishment of the agricultural experiment stations were especially noteworthy. Agriculture was a competitive industry, which meant that no individual farmer could devote any significant amount of resources to

As the twentieth century ends, both the share and the absolute amount of the world's resources devoted to the development of new knowledge are vastly greater than at the beginning of the century. Equally important is that the share of resources devoted to the wide distribution of that knowledge has also increased greatly.

VII. Population Growth—Roles of Fertility and Mortality

My third point is that population growth in the developed countries in the nineteenth century and in the developing countries in the twentieth century was due almost entirely to mortality declines and not to fertility increases. In other words, the response of men and women to improved circumstances—improved nutrition and higher incomes—was not to increase fertility significantly. For the nineteenth century the picture is clear. For the three European countries, both fertility and mortality declined. In England and Sweden there was an increase in fertility during the latter half of the eighteenth century but the increase was small (less than 10 percent) and lasted less than 50 years before declining throughout the nineteenth century. The increases in fertility had little or no effect on population growth in Europe, with a modest positive effect in Sweden and England from perhaps 1750 to 1800, but with declines throughout the nineteenth century.

The total fertility rate (average number of children per woman) for Sweden increased from 4.21 in 1750 to 4.68 in 1800 but then declined continuously throughout the nineteenth century, reaching a level of 1.90 in 1990 (Massimo Livi-Bacci, 1992 p. 122). Life expectancy in the last 20 years of the eighteenth century was 34 years, increasing to 39 years by 1835 and to 54 years in the first decade of the twentieth century (Nathan Keyfitz and Wilhelm Flieger, 1968 pp. 36–37).

Total fertility rates for England increased from 5.28 in 1750 to 5.87 in 1775 and then declined to 1.96 in 1900 (Livi-Bacci, 1989 p. 122). In the early period of the Industrial Revolution there seems to have been a small positive response in fertility to the improved circumstances that lasted less than half a century and had only a modest effect on the rate of population growth. In England life expectancy was 32 years in the last fifth of the seventeenth century and remained at that level in the years before 1750. It increased to 36 years by the end of the eighteenth century and to 41 years by the middle of the nineteenth century (Wrigley and Schofield, 1981 pp. 528–29) and continued to increase thereafter. In France the fertility and mortality trends are very clear—the total fertility rate was low in 1825 at 3.42 and fell continuously reaching 2.14 in 1900 (Livi-Bacci, 1992 p. 122). Life expectancy increased from about 28 years in 1760 to 40 years in 1840 and to 46 years at the end of the century (Wrigley, 1987 pp. 274).

The data on fertility and mortality available for the developing countries since 1960 prove that the source of the rapid population growth in these countries was the decline in mortality rather than an increase in fertility. In fact, both mortality and fertility fell much more rapidly in the developing countries in the twentieth century than in the developed countries in the nineteenth century prior to 1875.[7] Excluding China, which has had coercive restraints on fertility, the decline in fertility in the 31 lowest-income countries from 1960 to 1995 was 38 percent (United Nations Development Program [UNDP], 1998). Over the same period of time, life expectancy increased from 42 years to 59 years for the same countries. But the fertility decline lagged behind the mortality decline by a decade or more and high rates of population growth occurred in the 1960's and the 1970's. For example, between 1960 and 1978, in the 38

research. In addition, then and for at least the next century, the results of agricultural research were public goods—once a discovery was made, it became available to all. The private sector cannot afford to significantly invest in public goods. Today a significant fraction of agricultural research is undertaken in the private sector due to legal protection for intellectual property rights.

[7] The declines in total fertility rates in several European countries from 1875 to 1900 were very rapid—Germany, 48 percent; Sweden, 46 percent; England and Wales, 42 percent; Italy, 30 percent. In the United States the decline was 30 percent (Livi-Bacci, 1992 p. 122). These declines were actually greater than what occurred in a similar period in the low-income developing countries as a group but the declines occurred much later in the demographic transition.

low-income economies the crude death rate declined 31.5 percent while the crude birth rate declined 14.4 percent (China excluded) (World Bank, 1980). The annual population growth rate for the same countries was 2.5 percent for 1960–1970 and 2.2 percent for 1970–1978 (World Bank, 1980).

Why has fertility declined as real per capita incomes have increased? At low levels of income, with agriculture as the major occupation, children have a positive benefit in increasing the level of income of the parents as well as providing security against illness and old age. Children, and their growth and development, enter into the utility functions of parents positively. Parents realize satisfaction both in terms of the quantity and quality of their children (Becker, 1991). As real per capita incomes increase, the structure of the benefits from children change. The direct contribution of children to the income and material welfare of their parents diminishes and in urban communities becomes negative; even in agricultural communities where incomes and the level of mechanization are high, children make modest contributions to current incomes and fertility in rural and urban areas in the United States are now the same. However, the utility that parents derive from their children's growth and development increases as their incomes increase and the emphasis on the quality is reflected in increased investment in their children. Children have increasingly become a consumption good as real per capita incomes have increased. Thus the desired number of children is negatively related to real income and as contraceptive knowledge and technology have improved, families now have the ability to achieve the number of children desired to a greater degree and at lower cost than in decades past.

VIII. Why the Nineteenth Century Had Lower Population Growth

The differences in the population growth rates between Europe in the nineteenth century and in the developing countries in the twentieth century are very great. During the first half of the nineteenth century, the annual growth rate for Europe (excluding Russia) was 0.55 percent; from 1850 to 1880, 0.60, and for the last two decades, 0.80 percent. The annual rate of increase for the developing regions for 1950 to 1995 was 2.0 percent. In 1900 Europe's population (excluding Russia) was 285 million. If Europe's population during the nineteenth century had grown at the developing countries' rate from 1950 to 1995, its population would have exceeded a billion in 1900, more than three times its actual population. Could Europe have accommodated such a large population in 1900 without a significant reduction in its real per capita income at the end of the century? Obviously we will never know, but it seems very unlikely that it could have unless many of the technological developments of the twentieth century had occurred much, much earlier. While it was true that the rate of economic growth, as measured by changes in real GDP per capita, was much slower in Europe in the nineteenth century than in the developing countries in the twentieth century (Maddison, 1995), it is worth exploring why population growth was relatively slow in Europe.

One factor responsible for the slow growth of population in Europe was the significant increase in the percentage of the population living in cities—in 1800 the percentage was 12.1 and in 1900 it was 37.9. Throughout the nineteenth century, cities had much higher rates of mortality than rural areas. Migration from rural areas was the source of the growth of cities. Not only did death rates in cities exceed birth rates, but their death rates were significantly higher than in rural areas.

Bairoch (1988 p. 230) reports that in Western Europe throughout the nineteenth century infant mortality rates in urban areas exceeded the rates in rural areas by 30 to 60 percent. In Sweden in the early nineteenth century infant deaths accounted for approximately 25 percent of all deaths (Keyfitz and Flieger, 1968). But the difference in mortality was not confined to infants; life expectancy at age 15 in Sweden was more than four years higher in rural than in urban areas in 1881–1890 (Bairoch, 1988 p. 235).[8]

[8] The higher rates of infant mortality and mortality in general in urban than rural areas has long been well known to demographers. Wrigley and Schofield (1981 p. 415), for example, wrote as follows:

> ... the absence of any improvement in mortality in the second and third quarters of the nineteenth

The difference between population growth rates in the nineteenth and twentieth centuries was due primarily to the advancement of knowledge and technology that permitted much more rapid reductions in mortality in the twentieth century, even in the world's poorest countries. There was rather limited progress in reducing death rates until the midpoint of the nineteenth century in Sweden and significantly later for England. The basic environmental problems of unclean water, inadequate sanitation, and childhood infectious diseases still took a major toll until the early years of the twentieth century. The infant mortality rate in New York City in 1890 was 264 per 1,000 births, more than double the rate of 121 in rural areas (Weber, 1899).

The rates of decline in fertility in the developing world were greater than in the developed world for the periods under consideration. However, the crude birth rates in the developing world started their decline from a much higher level than existed in the developed world in the eighteenth and nineteenth centuries. The crude birth rates in Sweden and England in the eighteenth and early nineteenth centuries were in the range of 35 to 37 per thousand population while the averages for low-income countries in 1960 was 48 and the average for middle-income countries was 40 (World Bank, 1980). Consequently, the birth rate in the low-income countries needed to fall by a third just to reach the level prevailing in Western Europe at the beginning of the Industrial Revolution. The more rapid growth of population in today's developing world was not due to increases in fertility but to the combined effects of high initial rates of fertility and rapid declines in mortality.

IX. Wide Distribution of Benefits of Knowledge

In recent years a great deal of concern has been expressed about the lack of convergence of per capita income among countries and increasing inequality within countries. The emphasis on increased income inequality has left the impression that most measures of well-being have become much more unequal as well. The use of differences in per capita incomes as measures of either satisfaction or well-being assumes that these measures are proportional to income, a conclusion that cannot be supported.

Contrary to views that are widely held, for several important measures of well-being there has been great improvement, both absolutely and relatively, in the lives of the people of the low-income developing countries.[9] The benefits of the growth of knowledge have not been restricted to the countries responsible for the advances in knowledge but have spread throughout most of the world. And they would have spread more quickly and more widely if the policies of many governments had been more supportive of economic growth and development.

Improvements in the conditions of life in terms of nutrition, infant mortality, and life expectancy, have occurred at a much faster pace in the developing countries in the twentieth century than in the developed countries in the nineteenth century. These improvements have occurred with much larger populations and greater population densities. The population of the developing countries at the end of the twentieth century is 4.84 billion, an increase of 350 percent in a century. This compares to the increase in Europe in the nineteenth century of 85 percent. But not only did the improvements in well-being occur more rapidly during similar periods of economic development, but with respect to several very important variables the gaps narrowed significantly during the twentieth century and especially during the last half of that century.

century at a time of rapidly improving real wages is certainly due in part to the very rapid growth in the percentage of the population living in towns where the death rates were high. ... Better wages in the same economic and social environment may reduce mortality, but since better wages may also mean moving to a less healthy environment, there was a negative rather than positive relationship between wealth and health.

[9] For the countries that moved from low- to middle- or to high-income levels in the past half century, the improvements in terms of nutrition, infant mortality rates, and life expectancies have been significantly greater than what has occurred in countries that have remained low income. South Korea, Singapore, and Hong Kong are examples. Their infant mortality rates ranged from 4 to 11 per thousand in 1995 and life expectancy at birth from 72 to 79 years (World Bank, 1997), approaching the levels in Europe and North America. In 1950 their incomes were in the range of the current low-income countries.

A striking difference between the developing countries at the end of the twentieth century and the developed countries at the end of the nineteenth century is that the lowest-income countries have achieved rates of infant mortality and life expectancy that are significantly superior to those attained at the end of the nineteenth century in the developed countries.

The infant mortality rate for 30 low-income developing countries, including China, in 1960 was 157 per thousand births and it declined by 62 percent to 62 in 1996 (UNDP, 1998). The infant mortality rate in 1900 in nine European countries ranged from a low of 121 in Denmark to a high of 216 in Austria (Bairoch, 1988 p. 231). The rate in the United States was 160. The teeming cities of the developing world are often viewed negatively by observers from the developed world. A recent publication has the title "The Poverty of Cities in the Developing World" (Martin Brockerhoff and Ellen Brennan, 1997). Yet the study revealed that cities with a population of a million or more included in their sample had an infant mortality rate of 60 per thousand births in the 1990's (Brockerhoff and Brennan, 1997 p. 24). Two comparisons are relevant. Estimates of infant mortality for the first decade of the twentieth century were 500 to 600 for Bombay and 350 to 400 in Singapore (Bairoch, 1988 p. 450). The infant mortality rate in New York City at the beginning of the twentieth century was 264 (Weber, 1899 p. 346).

While infant mortality rates in cities in the developed world at the beginning of the twentieth century were higher than in rural areas, in the developing world the rates in the cities are now below those in rural areas (Brockerhoff and Brennan, 1997 p. 24). These data indicate both the large magnitude of the declines and the extent to which the improvements have been widely shared, even among many of the lowest-income families in the world.

Significant increases in life expectancy were achieved between 1900 and mid-century in the developing countries, though much greater absolute increases came later. The best available long-term data are for India, at least one benefit of being a British colony. Life expectancy in India in 1900 was 23 years, increasing to 32 years in the 1940's (Bogue, 1969 p. 572) and to 43 years in 1960 and 62 years in 1996.[10] Life expectancy increased by 170 percent in a century—it is now almost three times what it was a hundred years ago. Life expectancy in the world's poorest countries has increased since 1940 at a far more rapid rate than achieved in any country in the developed world in the nineteenth century. This is an area where there has been convergence between the rich and the poor countries over the past several decades. At the end of the nineteenth century life expectancy in seven industrial countries ranged from 46 to 51 (Bogue, 1969). In 33 low-income countries in 1996 life expectancy was 64 years, compared to 44 years in 1960, an absolute increase of 20 years (World Bank, 1998). Furthermore, the improvements in infant mortality and life expectancy have been achieved at lower levels of real per capita incomes than those prevailing in the developed countries at the beginning of the twentieth century (Maddison, 1995). The knowledge about the benefits of clean water and sanitation has been widely distributed and investments have been made to make those benefits widely available.[11]

Since the late 1940's there has been greater improvement in the world's availability of food than had occurred in all previous history. The evidence is the increase in per capita food supplies that occurred in the developing countries, with nearly 80 percent of the world's population. There are reasonably reliable estimates of daily per capita supply of calories for 1961–

[10] Other data on life expectancies indicate that in 1896–1997 it was 32 years in Russia and in 1900, 35 years in Spain (Bogue, 1969 pp. 576–77). The earliest estimates for several African countries are for the 1940's and 1950's and range from 27 to 40 years.

[11] The area of the world that appears to have participated least in the recent improvements in well-being is Sub-Saharan Africa. Per capita income measures show that in the majority of the countries real incomes have fallen in the last three decades. However, John Sender (1999) has shown that there have been significant improvements in infant mortality and life expectancy in the region. He estimates that in 1950 life expectancy was about 30 years, whereas a girl born in 1995 had a life expectancy of 54 years (Sender, 1999 p. 91). The unweighted child mortality rate (per thousand) for the 18 countries was 254 in 1960 and it declined to 139 in 1995, a decline of 45 percent. Sender shows that by a number of other measures, such as female enrollment rates in schools, the number of tractors, average grain yields, and the number of radio and television sets, substantial improvements occurred.

1963 when the daily per capita supply was 1,940 k/cals. In 1994–1996 the supply was 2,580 (Nikos Alexandratos, 1999 p. 5908)—a remarkable increase of 33 percent, given that population doubled during the period. Based on the increase in per capita grain production from 1948–1952 to 1961–1963, it can be estimated that the per capita calorie supply was about 1,700 in 1948–1952. The increase in calories per capita available in the developing countries from 1948–1952 to 1994–1996 was of the order of 50 percent.[12] Since developing countries produce at least 90 percent of the food they consume, this means that food production almost trebled in four decades! This could not have happened prior to the last half of the twentieth century; the knowledge that made it possible did not then exist.

Alexandratos (1999 p. 5908) provides a picture of the improvement in food supplies that adds another dimension to the increase in the per capita availability in the developing countries: " ... the part of the world population living in countries where per capita food supplies are still very low (under 2,200 k/cal/day) decreased considerably to only 10% in the mid-1990s, down from 56% 30 years earlier." Note that the 2,200 calories per day that is now defined as very low is somewhat higher than was available in England and significantly higher than in France in 1800, just two centuries ago. True, the average citizen of England and France as of 1800 was stunted and/or wasted—as short in height and low in weight—just as the average person in the developing countries with significantly less than 2,200 calories per day would be similarly designated today. What is important is that this level of consumption applies to countries with only a tenth of the world's population while 200 years ago it applied to nearly all of the world's population.

It is estimated that in 1990 approximately 780 million persons (19 percent of the developing-country population, down from 36 percent in 1969–1971) were malnourished (Alexandratos, 1995 p. 33). There is an adequate quantity of food now produced to provide these people with sufficient calories. However, as Adam Smith taught us, policies are an important factor determining how well a nation utilizes its resources. The majority of the malnourished people live in rural areas and most of them live in countries that have had policies that discriminated against agriculture and rural people for all or part of the last three decades. The most effective means to eliminate such malnutrition is to increase the incomes of farm people in these countries, something that would occur with more appropriate policies (Johnson, 1999 p. 52).

In my opening sentence I stated that not only are people better fed than ever before, but they acquire their food at the lowest cost in all history. There is no way to prove that the real cost per calorie is the lowest in all history, but we do know that nearly all people are now devoting a smaller percentage of their consumption expenditures to the acquisition of food than was true at times past. As recently as 1955 families in the United States allocated 23 percent of their consumption expenditure to food; today it is about 10 percent. For Japan the reduction was from 54 to 20 percent and for South Korea from 50 to 36 percent. Between 1960 and 1990 the food share in Thailand declined from 47 to 23 percent (United Nations, *National Account Statistics*). It is not unreasonable to assume that at the beginning of the nineteenth century in the developed countries that 70 percent or more of the consumption expenditures went for food and that the percentage was even higher at the beginning of the twentieth century for the developing countries.[13]

[12] Grain provides 75 to 80 percent of calories consumed in the low-income developing countries. From 1961–1963 to 1988–1990, per capita grain production increased by 25 percent, almost the same as the per capita increase in per capita calorie supplies. Data are available on grain production for 1948–1952. From that period to 1961–1963 per capita grain production increased by 14 percent. Thus one may estimate that per capita calorie supplies in 1948–1952 were approximately 1,700 (1,940/1.14 = 1,701).

[13] In discussing the benefits of the increase in knowledge and substantially higher incomes generated by that knowledge, I have said nothing directly about the possibility of environmental degradation. While in some and, perhaps, many respects the environment has been degraded in the twentieth century, in terms of the effects on life and overall health, the net effect has been strikingly positive. The declines in infant mortality and increases in life expectancy have been due largely to improved nutrition and environmental improvements in terms of sanitation and clean water. True, some features of the twentieth century, such as air

X. Concluding Comments

During the last two centuries, and especially in the twentieth century, there has been an enormous increase in knowledge that has been transformed into technology and ways of utilizing resources more efficiently. It is not only that knowledge has increased rapidly but the means of communicating that knowledge in an effective way have been markedly improved and the knowledge has become much more accessible throughout the world.

The rapid growth of knowledge has resulted both from the growth of the world's population and the increase in the percentage of that population that is now able to devote time and energy to the creation of knowledge. It was not so long ago that farmers accounted for 80 percent of the world's labor force and they barely produced enough for themselves with little left for exchange. As productivity in agriculture increased, the rapid growth of cities occurred and the growth in real per capita incomes exceeded what had ever been achieved before. The fact that during the 1980's the increase in the world's output was ten times what world output was in 1820 illustrates how great has been the growth of output in a very brief period of time.

But perhaps the greatest achievement of the twentieth century is that the majority of the poor people of the world have shared in the improvements in well-being made possible by the advancement of knowledge. Three measures show how great these improvements have been—infant mortality rates, life expectancy, and per capita food supplies. The large cities of the developing world now have infant mortality rates about a quarter of those of New York City in 1890. True, there is much more that can be done to share more fully the benefits of the knowledge base. And I am confident that whoever speaks from this platform just 25 years from now could point to further dramatic reductions in worldwide inequalities in well-being.

pollution, do have an adverse effect on life expectancy, but these effects are probably measured in months rather than years. But those of us who live in high-income countries often consider problems from the standpoint of our environment, not the environment facing the majority of the world's population. For example, with respect to air pollution, the World Health Organization has estimated that in the world in 1996 there were 2.7 million deaths from air pollution (UNDP, 1998 p. 70). However, less than 7 percent were in industrial countries. Of the 2.5 million deaths in developing countries, almost 2.2 million deaths were attributed to indoor air pollution, not to outdoor pollution, and most were in rural areas. As real incomes in the developing countries increase, leading to improvements in the quality of housing and the replacement of indigenous fuels by modern fuels, the adverse environmental effects of air pollution will be significantly reduced.

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