# World Population in 2050: Assessing the Projections

**Joel E. Cohen***

This paper will review some population projections for the United States, the world, and selected major regions. The total population size, the youth dependency ratio, the elderly dependency ratio, and the total dependency ratio will receive most attention. The underlying assumptions regarding fertility, mortality, and migration will be reviewed. Projections from different sources will be compared where possible.

But before looking to the future, I thought that it would be useful to have a glimpse into the past. Two thousand years ago, we had about a quarter of a billion people on the planet. It took sixteen to seventeen centuries to double to about one-half billion. The next doubling took less than two centuries, from the middle of the seventeenth century to around 1800. The next doubling took little over 100 years, and standing where we are now and looking back, the last doubling took about thirty-nine years. The second half of the twentieth century is the first time in all of human history in which the Earth's population doubled within a single lifetime. That is a fortyfold acceleration in the population growth rate, and there is no precedent for that.

The projections to be reviewed here were prepared by the United Nations Population Division (1999a,b,c) (henceforth abbreviated to UN98) and the United States Census Bureau (1998 and 2000a) (henceforth abbreviated to US98 for the international projections, and US00 for the domestic projections, respectively). Estimates and projections of total midyear population for the world, 1950 to 2050, updated to May 10, 2000,

*Professor of Populations, Rockefeller University and Columbia University. The author acknowledges with thanks the support of U.S. National Science Foundation grant DEB 9981522 and the hospitality of Mr. and Mrs. William T. Golden during this work.

Table 1
Demographic Features of the More Developed Regions and the Less Developed Regions, 1950-2050, according to the United Nations' Medium Projection 1998 (United Nations 1999a,b,c).

| Indicator | More Developed Regions | | | Less Developed Regions | | |
|---|---|---|---|---|---|---|
| Year | 1950 | 2000 | 2050 | 1950 | 2000 | 2050 |
| Population growth rate (%/y) | +1.2 | +.3 | −.3 | +2.0 | +1.6 | +.5 |
| Total fertility rate (children) | 2.8 | 1.6 | 1.8 | 6.2 | 3.0 | 2.1 |
| Population size (billions) | 0.81 | 1.19 | 1.16 | 1.71 | 4.87 | 7.75 |
| Percent urban | 54.9 | 76.0 | 83.5[a] | 17.8 | 39.9 | 56.2[a] |
| Percent aged 0-4 years | 10.0 | 5.5 | 5.0 | 15.1 | 11.1 | 6.8 |
| Percent aged 60+ years | 11.7 | 19.5 | 32.5 | 6.4 | 7.7 | 20.6 |
| Ratio 60+ years/0-4 years | 1.2 | 3.5 | 6.5 | .4 | .7 | 3.0 |
| Median age (years) | 28.6 | 37.5 | 45.6 | 21.3 | 24.4 | 36.7 |
| Youth dependency ratio (%) | 42.2 | 27.0 | 25.8 | 64.7 | 52.1 | 31.7 |
| Elderly dependency ratio (%) | 12.2 | 21.3 | 42.7 | 6.7 | 8.2 | 21.1 |
| Total dependency ratio (%) | 54.4 | 48.3 | 68.5 | 71.4 | 60.3 | 52.8 |
| Females 80+/Males 80+ | 1.74 | 2.26 | 1.82 | 1.46 | 1.57 | 1.58 |
| Net migration (millions) | n.a. | +2.0 | +1.3 | n.a. | −2.0 | −1.3 |
| Population density (per km$^2$) | 15 | 22 | 22 | 21 | 59 | 94 |
| Gross national product per person (US$, 1998) | $19,480 | | | $1,260 | | |

[a]Projected for year 2030, not for year 2050. n.a. = not available.

Source: All estimates except percent urban are from United Nations (1999a, pp. 10-13, pp. 592-617; 1999b, pp. 14-19). Percent urban is from United Nations (2000, p. 4). GNP per person in 1998 is from Population Reference Bureau (2000, p. 2), attributed to the World Bank, *World Development Report, 2000*.

are available on the web (U.S. Census Bureau 2000b) and will be cited here when these figures replace those of US98. Table 1 summarizes some major results for the more developed countries and the less developed countries separately, for the years 1950, 2000, and 2050.

## Cautionary Tales

In April 2001, the U.S. Census Bureau announced that the total population of the United States on April 1, 2000, was 281,421,906. The apparent precision was entirely spurious. The Director of the Census Bureau later remarked that the true population of the United States in 2000 is known only to within 5 million persons or so.

In the week the Census 2000 total count was announced, the Internet web site of the Census Bureau continued to report the estimated population of the United States in 2000 as about 275 million. This lower figure was based on annual Census Bureau estimates of births, deaths, and migration since the 1990 census of the United States. The estimate of 275 million differed from the counted population of 281 million in 2000 by

at least as much as the 5 million estimated error of the count. Evidently it is difficult to measure or estimate what happened recently and is happening currently to the population of one of the richest countries with one of the best statistical infrastructures in the world.

On a global scale, in the United Nations' *Demographic Yearbooks* from 1951 to 1996, the estimate of world population in 1950 changed seventeen times, upward thirteen times and downward four times (National Research Council 2000, p. 42). The difficulty of ascertaining the present and the past population compounds the difficulty of anticipating the future population of a country, region, or the world. Errors in the base population have been the largest component of error in past short-term population projections (National Research Council 2000).

According to a preliminary announcement of the United Nations Population Division (2001), the difference between the medium projected population of the world in 2050 according to its 1998 projection (8.9 billion) and its 2000 projection (9.3 billion) is 413 million people, roughly 5 percent of the 1998 projected population size for 2050. The population project at the International Institute for Applied Systems Analysis (Lutz, Sanderson, and Scherbov 2001) projected a median (not medium) world population in 2050 of 8.8 billion. These three projections for 2050 differ in methods and assumptions. The differences in output among them of half a billion people express demographers' ignorance of the future, not differences in genuine knowledge. Because the full details of the United Nations Population Division's 2000 projections are not yet available, this review will rely on the 1998 projections (United Nations Population Division 1999a,b,c).

## UNCERTAINTY

The demographic present, past, and future are surrounded by uncertainty. Population projections are uncertain for several reasons. The initial data may be erroneous. The rates of birth, death, and migration in cohort-component models may be projected erroneously. (Projections for countries or small areas normally are more uncertain than those for the world because of the greater importance of migration for local areas.) External factors may change unexpectedly (such as AIDS, natural hazards, or climate). External factors may change as expected but the relationship between those factors and demographic rates may change. Policies and programs may develop to influence the rates of birth, death, and migration. Feedbacks from anticipated population change may intervene to alter further population change in unanticipated ways (for example, if the prospect of population decline in Italy or Japan affects the immigration policy of those countries). The social sciences have little ability to predict the aggregate course of the fundamental demographic

processes of birth, death, and migration (National Research Council 2000; Cohen 2001).

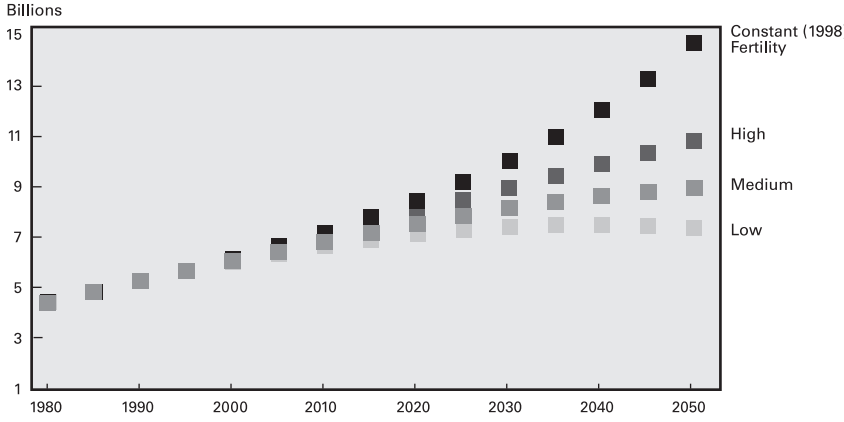
A recent report of the National Research Council (2000) gives a sophisticated assessment and a quantitative analysis of the uncertainty of population projections, which this brief paper will not attempt to duplicate. The development of techniques to assess the uncertainty of population projections realistically is an active area of research (Alho 1997; Alho and Spencer 1990; Anderson, Tuljapurkar, and Lee 1999; Keilman 1990, 1997, 1998; Keyfitz 1982; Lee 1990, 1999, 2000a, b; Lee and Tuljapurkar 1994 and in press; Lutz, Sanderson, and Scherbov 1997; Lutz, Goujon, and Doblhammer-Reiter 1999; and Tuljapurkar and Boe 1998, among many others).

In addition to the UN Population Division and the U.S. Census Bureau, other agencies and organizations prepare population projections for the United States and the world. Among these organizations are the World Bank (World Bank 2000), the International Institute for Applied Systems Analysis (Lutz 1996; Lutz, Sanderson, and Scherbov 2001), the Social Security Administration of the U.S. government (Bell 1997), and some statistical agencies of national governments. The detailed assumptions of the projections prepared by these organizations differ. However, the data, methods, and assumptions used are sufficiently similar that the global population projections prepared by different agencies normally do not vary greatly (National Research Council 2000). This consensus should not be taken as grounds for confidence in the results of the projections. Demographers talk to each other and review each other's work. Retrospective reviews of the accuracy of population projections indicate that the confidence attached to many projections has been greater than the subsequent accuracy of the projections would justify (National Research Council 2000).

## Major Population Trends in the Next Half Century

Most demographers would probably agree to four statements about the future of global population during the next quarter- to half-century. First, the population will be bigger than it is now. The world will be bigger by 2 billion to 4 billion people by the middle of the century, and nearly all of that growth will be in poor countries, not rich. Second, the population will increase less rapidly, absolutely and relatively, than it has recently. Whether population growth ends depends on choices that we make right now about reproductive health, education for women, and many other investments. Third, the population will be more urban than it is now. Practically all of the additional people will be living in cities in poor countries, and that will be an unprecedented epidemiological challenge to infectious disease control. Fourth, the population will be older than it is now. Now is probably the last time in history in which we

**Figure 1**
**World Population, United Nations 1998 Projections**




Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Vol. 1, Table A1.

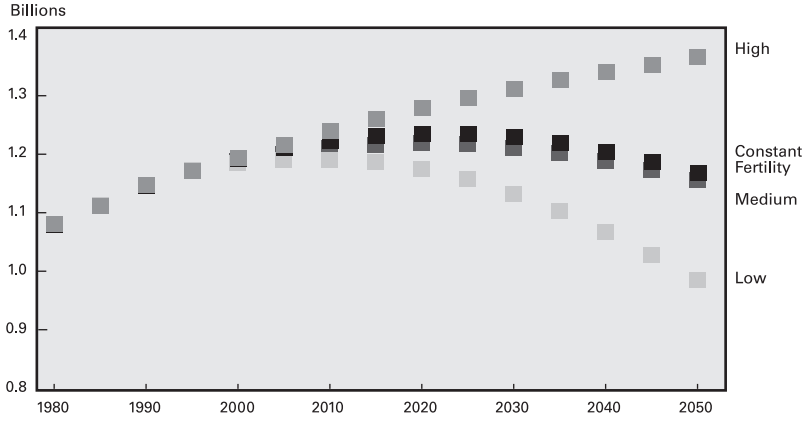
have more youth than aged, and the last time in which we have more rural than urban population. From here on out it is an urban world. Here are some details on each of these statements.

## Continuing Population Growth in the Developing World

The twenty-first century is unlikely to see a reversal of world population growth for several decades at least. More young people are entering their childbearing years now than ever before in history. UN98 projected an increase in world population from 6.06 billion in 2000 to 8.91 billion in 2050 in its medium projection, an increase of 47 percent. The U.S. Census Bureau (2000b) projected an increase in world population from 6.08 billion in 2000 to 9.10 billion, an increase of 50 percent. (Here and elsewhere, I calculated percentage increases using unrounded figures, then rounded the result.) Although US00 gave only a single projection of global population, UN98 indicated a range in 2050 from 7.3 billion people in its low variant projection to 10.7 billion in its high variant. If fertility were to remain constant at the levels estimated in 1998, the year 2050 would see 14.4 billion people (Figure 1).

The long-term projections based on the UN98 low projection calculated that global population will peak near 7.5 billion around 2040 and will fall to 5.2 billion by 2100 (United Nations 1999d, p. 29). The world previously had 5.2 billion people between 1985 and 1990. Unless future population growth is much lower than anticipated in the low projection,

**Figure 2**
**Population of More Developed Countries,**
**United Nations 1998 Projections**



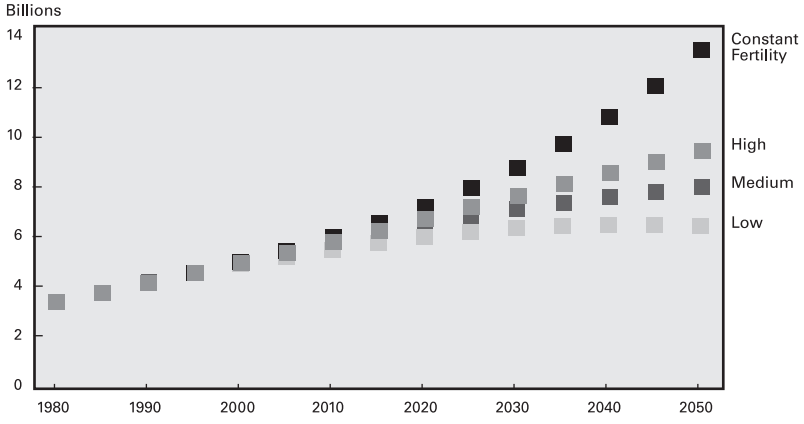

Data: U.N. Population Division, *World Population Prospects: 1998 Revision,* Vol. 1, Table A1.

the twenty-first century will have billions more people than the twentieth century.

The population of the more developed regions will decline slightly (Figure 2) while that of the less developed regions will increase substantially (Figure 3), according to the U.N.'s best guess. In the medium projection of UN98, the population of the more developed countries will decline between 2000 and 2050 by 3 percent from the present 1.19 billion, while the population of the less developed countries will grow from the present 4.87 billion by 59 percent (Figure 4). The more developed countries comprise Northern America (the United States and Canada), Japan, Europe, Australia, and New Zealand. The less developed countries comprise all regions of Africa, Latin America, the Caribbean, Asia (excluding Japan), Melanesia, Micronesia, and Polynesia. The calculations assume that the classification of countries as more developed and less developed will not change in the coming half-century. In this case, the fraction of world population living in the more developed regions would fall to under 13 percent, or approximately one person in eight.

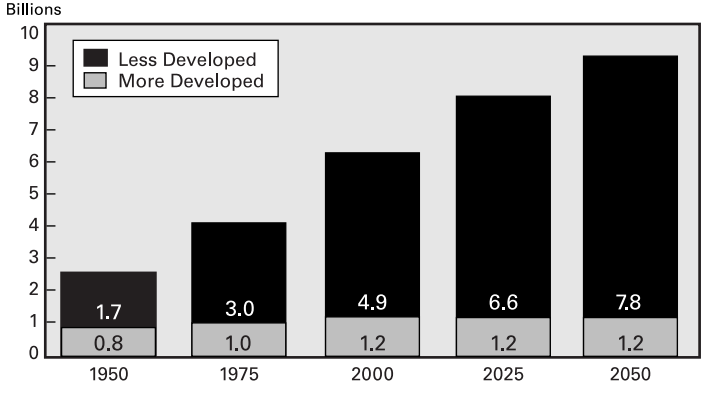
The population of the now least developed countries, a subset of the less developed countries, is projected in the medium variant to increase by 132 percent, from 645 million in 2000 to 1.49 billion in 2050, surpassing the total population of the more developed regions by 2035 (Figure 5).

**Figure 3**
**Population of Less Developed Countries, United Nations 1998 Projections**



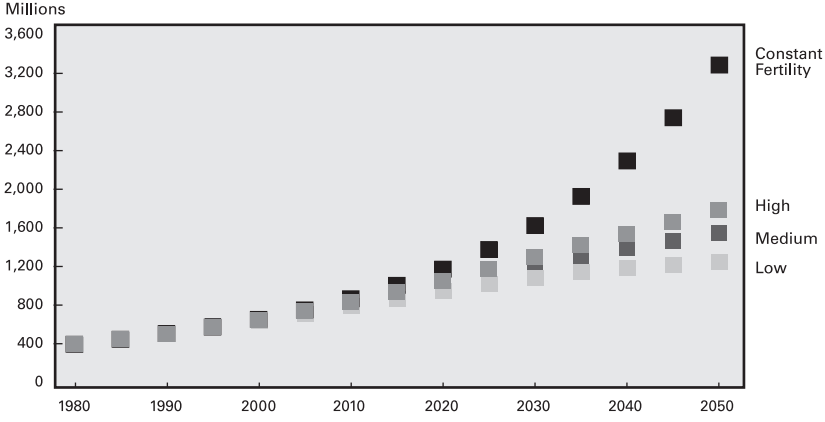

Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Vol. 1, Table A1.

**Figure 4**
**Population of the More and Less Developed Countries, United Nations 1998 Medium Projections**




More developed countries: United States, Canada, Japan, Europe, Australia, and New Zealand.
Less developed countries: All regions of Africa, Latin America, the Caribbean, Asia (excluding Japan), Melanesia, Micronesia, and Polynesia.
Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Vol. 1, Table A1.

**Figure 5**
**Population of Least Developed Countries, United Nations 1998 Projections**




Least developed countries: 33 countries in Africa, nine in Asia, one in the Caribbean, and five in Oceania.
Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Vol. 1, Table A1.

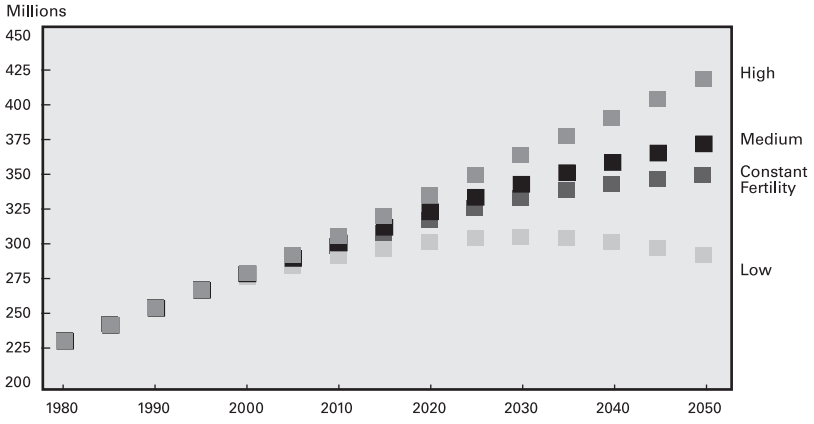
The least developed countries include thirty-three countries in Africa, nine in Asia, one in the Caribbean, and five in Oceania.

The conclusion that the population of the more developed countries will be a small and diminishing fraction of global population is not sensitive to the fertility assumptions of the UN98 medium projection. In the UN98 low projection, the population of the more developed countries falls from 1.2 billion in 2000 to 1.0 billion in 2050, while the population of the less developed countries rises from 4.8 billion to 6.4 billion in the same half-century. In the constant fertility projection of UN98, the population of the more developed countries remains flat at 1.2 billion, while the population of the less developed countries surges to 13.3 billion by 2050. The constant fertility projection is not realistic or plausible, but it illustrates what could happen if fertility fails to fall as anticipated in the other projections.

The population density in the more developed countries is currently about 22 people per square kilometer, while that in the less developed countries is roughly 59 people per square kilometer (UN98, pp. 10, 12). The latter number would grow to 94 according to the medium projection, or nearly one person per hectare. Attaining acceptable qualities of life in developing countries at such population densities will be an even greater challenge than it is at today's population densities.

The population of the United States will be larger in 2050 than in

**Figure 6**
**United States Population, 1980 to 2050,**
**United Nations 1998 Projections**



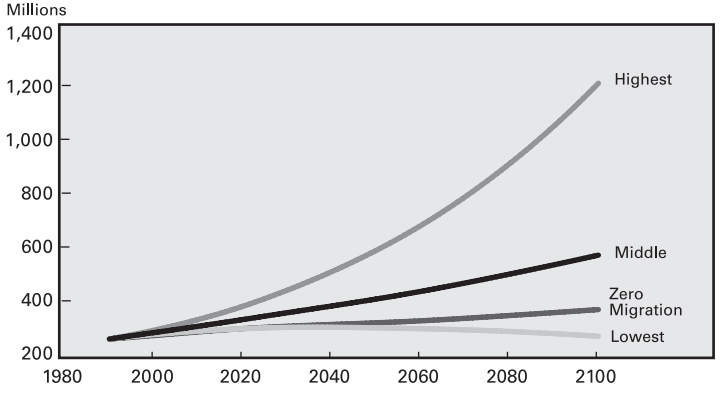

Source: U.N. Population Division, *World Population Prospects: 1998 Revision*. Vol. 1, Table A2.

2000 according to all projections of UN98 (Figure 6). The U.S. population is projected to grow by 25 percent (to 349 million) in the UN98 medium projection, 50 percent (to 419 million) in the high projection, and 6 percent (to 293 million) in the low projection. In the low scenario, the population would peak at 305 million in 2030, then decline.

By contrast, US00 projected roughly twice as much population growth for the United States in its corresponding middle, high, and low series (Figure 7): 47 percent population growth (to 404 million) by 2050 in its middle series, 100 percent (to 553 million) by 2050 in its high series, and 14 percent (to 314 million) by 2050 in its low series (Figure 8). All these projections are based on an estimated 1998 population for the United States of 270 million, leading to projected U.S. populations in 2000 of 275 or 276 million, lower than the Census 2000 count of 281 million. The medium projection of US00 is strikingly close to the high projection of UN98 in 2050, while the low projection of US00 is not much less than the medium projection of UN98 in 2050. These respected agencies have differing operational definitions of low, medium, and high projections. According to the highest US00 scenario, by 2100, the United States would have approximately the population of China today.

To assess the impacts on United States population growth and dependency ratios of different assumptions about international migration, Hollmann, Mulder, and Kallan (2000, p. 29) combined the mortality

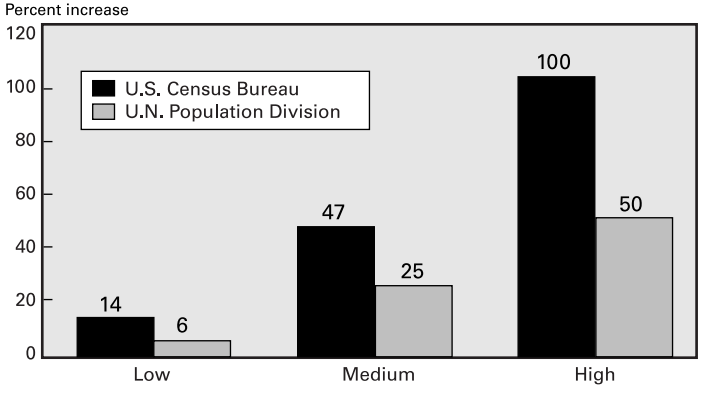
**Figure 7**
**United States Population, 1990 to 2100,**
**U.S. Census Bureau Projections**




Data: U.S. Census Bureau, Estimates and Projections Programs, Population Division, NP-T1, February 14, 2000.

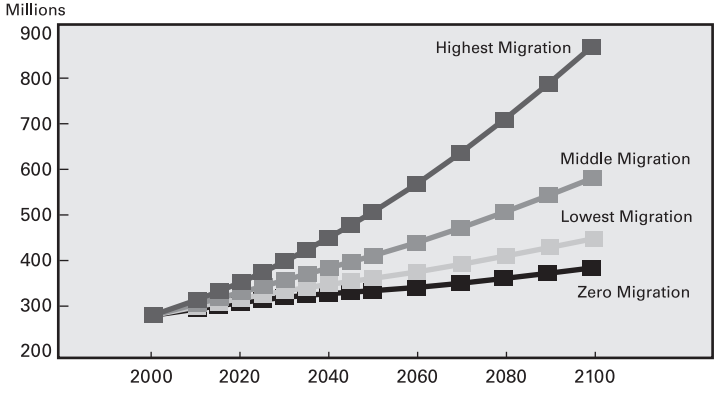
and fertility assumpions of the US00 middle series with three other assumptions about international migration after 1998, namely, zero international migration, lowest migration, and highest migration (Figure 9). Assuming zero international migration, the population of the United

**Figure 8**
**Estimates of U.S. Population Growth, 2000 to 2050**




Data: U.S. Census Bureau, Estimates and Projections Programs, Population Division, NP-T1, February 14, 2000. U.N. Population Division, *World Population Prospects: 1998 Revision,* Vol. 1, Table A2.

**Figure 9**
**Projected U.S. Population under Four International Migration Scenarios**

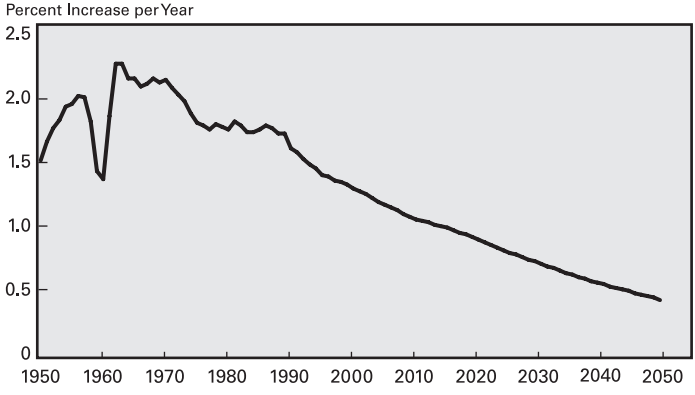



Data: U.S. Census Bureau, Population Division, Working Paper 38, January 13, 2000, Table F, p. 29.

States is projected to grow from 274 million in 2000 to 328 million in 2050, an increase of nearly 20 percent. The middle series assumes that net international in-migration per year is mainly between 900,000 and 1 million. Under this assumption, the U.S. population increases by 47 percent (to 404 million) from 2000 to 2050. Therefore, international migration would, according to the assumptions of the middle series, account for about 27/47 or 57 percent of projected U.S. population growth between 2000 and 2050. Assuming the lowest level of migration (net migration to the United States diminishing from 739,000 in 1999 to 166,000 in 2050), the U.S. population is projected to grow by 29 percent (to 353 million), a bit more than half the growth projected in the middle series. Assuming the highest level of migration (net annual migration to the United States increasing from 1.2 million in 1999 to 2.8 million by 2050), the U.S. population is projected to grow by 80 percent (to 498 million) by 2050. Differing assumptions about the level of international migration have very large effects on the size of the U.S. population by 2050, and still larger effects later. The effects on dependency ratios are described below.

Ahlburg and Vaupel (1990) independently prepared several alternative projections of U.S population, starting from a 1990 population of 250 million. Assuming an annual improvement in mortality of 1 percent, a total fertility rate of two children per woman, and 1 million to 2 million immigrants per year, they projected 402 million people in the United States by 2050. With an annual improvement in mortality of 2 percent but

**Figure 10**
**World Population Growth Rate**
**1950 to 2050**




Data: U.S. Census Bureau, International Data Base, May 10, 2000.

other assumptions the same, they projected 430 million people by 2050. With 2 percent mortality improvements, moderate fertility cycles, and 1 million immigrants per year, they projected 470 million people. With 2 percent mortality improvements, large fertility cycles, and 1 million to 2 million immigrants per year, they projected 553 million people by 2050. Except for the last, these projected population sizes are generally consistent with the range of population sizes projected for the United States by Hollmann, Mulder, and Kallan (2000) and US00.

## Slowing Population Growth Everywhere

In the twentieth century, world population increased 3.8-fold. World population is very unlikely to increase 3.8-fold in the twenty-first century. Lutz, Sanderson, and Scherbov (1997, 2001) have suggested that population growth rates will decline so rapidly that even another doubling of the Earth's population is unlikely ever to occur. At the end of the twentieth century, after thirty-five years of slowing population growth, a continued slowing in the twenty-first century seems likely. If the rate of increase of population continues to fall, then the twentieth century was and will be the only century in the history of humanity to see a doubling of earth's population within a single lifetime. Human numbers will probably never again nearly quadruple within a century.

Global population growth rates varied so erratically from 1950 to 2000 (Figure 10) that the expectation of a continuing smooth decline in

population growth rates in the coming half-century seems implausible. What is plausible is that the overall trend will continue in a downward direction much of the time. The medium variant of UN98 projected a decline in the population growth rate per year from 1.33 percent between 1995 and 2000 to 0.38 percent between 2040 and 2050, and a fall in the absolute annual increment from 78 million to 33 million additional people. The U.S. Census Bureau (2000b) International Data Base (updated to May 10, 2000) projected a decline in global population growth rates from 1.26 percent to 0.43 percent per year between 2000 and 2050, and a fall in the absolute annual increment from 77 million to 39 million. The medium UN98 projection has a slightly higher estimate of annual growth in 2000 and a slightly lower projection of annual growth in 2050, but the differences are immaterial considering the uncertainty of demographic estimates and projections.

**More Urbanization**

In Europe, the rush of people from the countryside to cities dates back to the eleventh century, and urbanization has occurred worldwide for at least two centuries. During the 1990-95 period, the world's urban population grew by 2.4 percent per year, while rural populations grew 0.7 percent per year (United Nations 1997). Between 1995 and 2000, the world's urban population grew by 2.1 percent per year while rural populations grew 0.7 percent per year. In 1999, nineteen urban agglomerations had 10 million people or more and 47 percent of all people lived in cities (United Nations 2000).

The twenty-first century is unlikely to see a reversal in the relative growth of urban population. Almost all population growth in the next thirty years will be located in cities in the less developed regions. The rural population of the world will remain nearly constant at around 3.2 or 3.3 billion people (United Nations 2000, p. 2). The rural population will continue its slow decline in the more developed countries. In the less developed countries, the rural population will peak at around 3.1 billion people in the next decade or two, then slowly decline. If urbanization occurs as anticipated, then the twentieth century was and will be the last century in human history in which most people live in rural areas.

In the next century, humanity will be predominantly urban. According to recent projections (United Nations 2000), the urban population will rise to 60 percent of the total by 2030 (84 percent of the population in more developed regions, 56 percent of the population in less developed regions). By 2030, the urban population will total 4.9 billion, 1.0 billion in the more developed regions and 3.9 billion in the less developed regions. The 2030 urban population in the less developed regions projected in the 1999 United Nations report on urbanization (United Nations 2000) is smaller by 200 million people than the 2030 urban population in the less

developed regions projected in the 1996 report on urbanization (United Nations 1997). Evidently, the population growth rate of urban areas in the less developed regions has dropped faster than anticipated.

US98 relied in part on the 1996 urbanization projections of the UN (United Nations 1997) for its estimates of urban population in 1998 and 2025. US98 projected that nearly 60 percent of world population would be urban by 2025.

These figures on urbanization disguise major ambiguities and variations among countries in definitions of "cities" and "urban." Neither US98 nor United Nations (2000) discusses the conceptual problems of the numerical data on urbanization. The numbers should not be taken literally, but the trend toward urbanization is clear.

## Aging of the Population

*Median age.* The median age of a population is the age such that half the people are older and half are younger. The median age of world population rose from 23.5 years in 1950 to 26.6 years in 2000 (UN98, p. 8). By 2050, the median age will rise to 37.8 years according to the UN98 medium projection, to 33.0 years according to the high projection, and to 43.5 years according to the low projection. The median age will increase by 10 to 20 years in the century from 1950 to 2050. In the same century, the median age of the more developed regions is projected to increase by 17 years while that of the less developed regions increases by 15.4 years, even though the more developed regions started with a median age 7.3 years older than that of the less developed regions (Table 1).

For comparison, US98 (p. 33) estimated world median age in 1998 as 26 years (versus UN98's median of 26.6 years in 2000), and projected median ages in 2025 for the more developed countries, less developed countries, and the world as 43, 30, and 32 years. The corresponding projections of the medium variant of UN98 (pp. 8-12) were 43.6, 30.9, and 32.7 years. The median age is a useful single-number summary of population age but does not make explicit the decrease in the proportion of young people and the increase in the proportion of old people that accompany population aging.

*Proportions of young and old.* In the twentieth century, the fraction of the world's people who were children aged 0 to 4 years gradually declined to 10 percent in the year 2000, while the fraction of the world's people who were aged 60 years or more gradually increased to 10 percent in the year 2000 (UN98). These converging trends resulted from improved survival and reduced fertility. Improved survival raised the world's expectation of life from perhaps 30 years (a plausible guess, given the absence of reliable global statistics) at the beginning of the twentieth century to more than 66 years at the beginning of the twenty-first century.

Reduced fertility rates (Table 1) added smaller cohorts to the younger age groups.

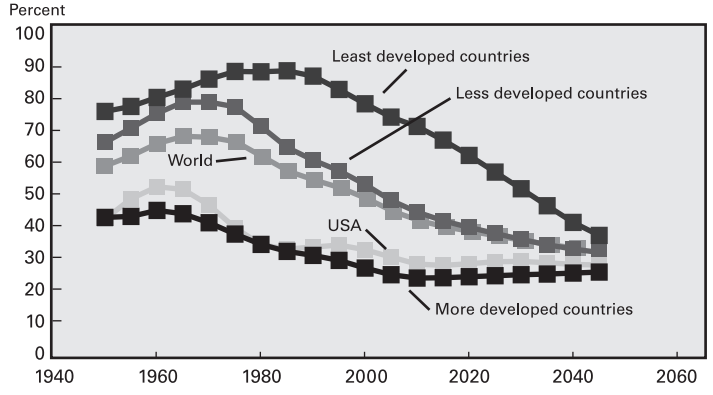
The twenty-first century is unlikely to see a reversal in the aging of world population. UN98 projected that by 2050, the fraction of the population aged 0 to 4 years will fall from 10 percent to less than 7 percent while the fraction of the population aged 60 years or more will rise from 10 percent to more than 22 percent. In this projection, the ratio of older people to young children is expected to rise from 1-to-1 now to 3.3-to-1 in half a century. In all the variant projections of UN98, the ratio of elderly to young children is expected to grow. The lower future fertility is, the higher the ratio of elderly people to young children will be. If the future resembles any of the UN98 projections, then the twentieth century was and will be the last century in human history to see younger people outnumber older people. The next century will be a world predominantly of older people.

*Dependency ratios.* Economists and some demographers prefer to summarize the age structure of a population using dependency ratios. The youth dependency ratio is defined as the ratio of the number of people aged 0 to 14 to the number aged 15 to 64. The elderly dependency ratio is defined as the ratio of the number of people aged 65 and older to the number aged 15 to 64. The total dependency ratio is defined as the sum of the youth dependency ratio and the elderly dependency ratio. All three dependency ratios are normally expressed as percentages.

Assuming that the potential labor force of a population is aged 15 to 64 years, the reciprocal of the total dependency ratio may be interpreted as the number of potential workers available per dependent person (young or elderly). For example, if the total dependency ratio is 50 percent or 0.5 (as it nearly was in the United States in 2000), the reciprocal $1/0.5 = 2$ means that the population has two potential workers for each person of dependent age. The reciprocals of the youth dependency ratio and the elderly dependency ratio have similar interpretations. The higher the dependency ratios, the lower the numbers of potential workers available to support the dependents.

*Dependency ratios in the world and in major regions*. In the world as a whole, in the more developed countries, in the less developed countries, in the least developed countries, and in the United States, the youth dependency ratio rose with the surge of fertility that followed World War II, peaked, and declined in the final decade or two of the twentieth century (Figure 11). The youth dependency ratio reached its peak earliest, around 1960, in the United States and the more developed countries, then in the world as a whole around 1965, around 1970 in the less developed countries, and as late as 1985 in the least developed countries. According to the UN98 medium projection, in the twenty-first century, the youth dependency ratio will continue to decline for the less developed and least developed countries and for the world as a whole. The slight increase in

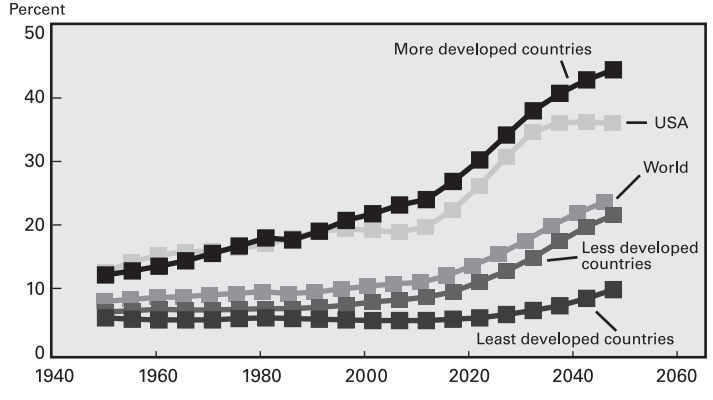
**Figure 11**
**Dependency Ratios for Youth Ages 0 to14**
**United Nations 1998 Medium Variant**




Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Volume 1, Table A29.

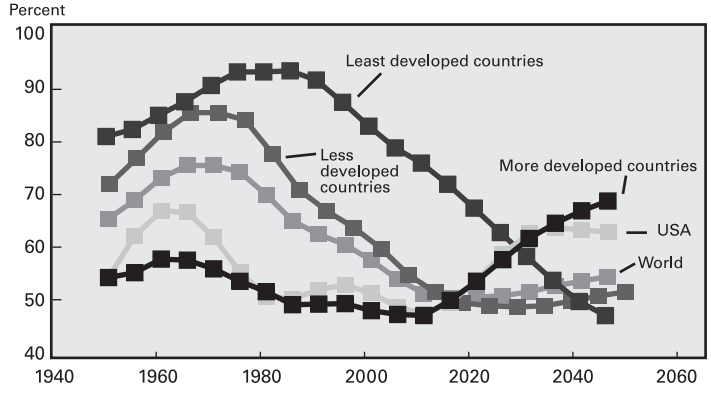
the youth dependency ratio in the United States and the more developed countries probably follows from the arbitrary assumption (see *Fertility assumptions*, below) that fertility will rise in these countries from its present levels, which are currently significantly below replacement level.

**Figure 12**
**Dependency Ratios for Elderly Ages 65 and Older**
**United Nations 1998 Medium Variant**




Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Volume 1, Table A29.

**Figure 13**
**Total Dependency Ratios**
**United Nations 1998 Medium Variant**

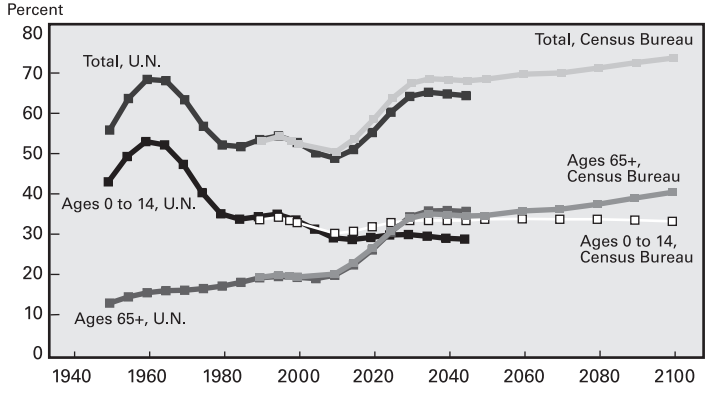



Data: U.N. Population Division, *World Population Prospects: 1998 Revision*, Volume 1, Table A29.

The elderly dependency ratio rose from 1950 to 2000 at a rapid rate in the more developed countries, slightly less rapidly in the United States, and still less rapidly in the world as a whole. The ratio rose only slightly in the less developed countries, and hardly at all in the least developed countries (Figure 12). According to the UN98 medium projection, after 2010, the more developed countries, the United States, and even the less developed countries will experience a sharp acceleration in the rate of increase of the elderly dependency ratio. This acceleration will be greater in the more developed countries and the United States than in the less developed countries. The least developed countries will experience a slow increase in the elderly dependency ratio following 2020 and by 2050 will be approaching the elderly dependency ratio of the more developed countries in 1950.

The total dependency ratio of the world grew from 1950 to 1965-70. It has steadily fallen since then (Figure 13). According to the medium projection of UN98, the total dependency ratio will reach a minimum around 2015 and then slowly ascend, as the elderly subpopulation will increase faster than the youthful subpopulation will decrease. This total dependency roller coaster (a pattern of a rising, falling, and again rising total dependency ratio) is observed and projected for each region, although the final rise for the least developed countries does not occur before the end of the projection interval in 2045-50. The US98 (p. 36) dependency ratios for the world, the more developed countries, and the less developed countries projected for 2025 differ from the corresponding

**Figure 14**
**U.S. Dependency Ratios**
**United Nations 1998 Medium Variant and**
**U.S. Census Bureau 2000 Middle Series**



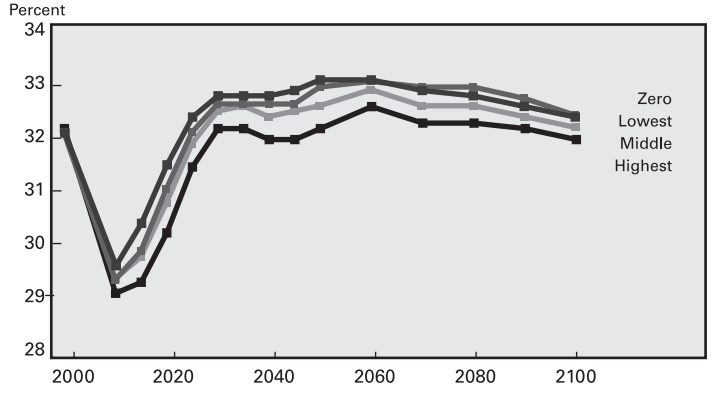

Data: U.N. Population Division, *World Population Prospects: 1998 Revision,* Volume 1, Table A29; U.S. Census Bureau, Working Paper 38, January 13, 2000, Table F, p. 29.

dependency ratios of the UN98 medium projection by not more than 1 or 2 percentage points, and generally much less.

The likelihood that all regions of the world will experience a total dependency roller coaster of similar form may matter much less for the coming two or three decades than the difference between the more developed countries and the less developed countries in where they now are on that roller coaster. For the first quarter of the twenty-first century, the UN98 and US98 projections anticipate a declining total dependency ratio in the less developed countries, but (at least after 2010) an increasing total dependency ratio in the more developed countries. The trough in the total dependency roller coaster corresponds to a peak in the number of potential workers per dependent person. While the less developed countries are approaching that peak in the number of potential workers per dependent, commonly referred to as a "demographic bonus," the more developed countries are currently passing through that peak and soon will be rapidly rolling away from it.

*Dependency ratios in the United States.* The UN98 and US00 estimates of the three dependency ratios for the United States are virtually identical for the 1990-2000 decade (Figure 14). The projected dependency ratios (in the medium UN98 and the middle US00 projections) differ systematically but not by more than a few percentage points for the coming half-century. Because, as remarked above, UN98 projected less rapid population

**Figure 15**
**U.S. Youth Dependency Ratios under Four Migration Scenarios**

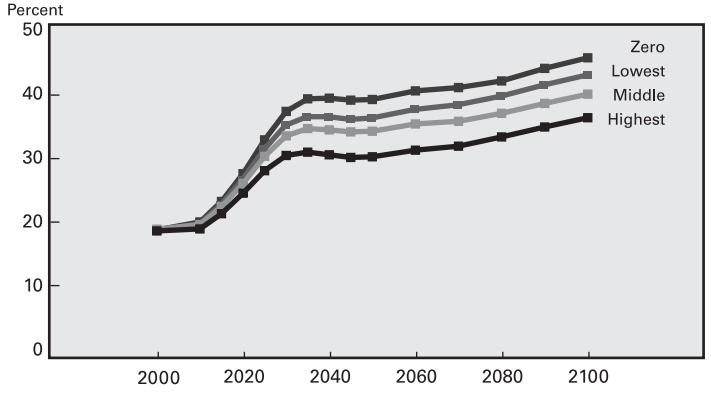



Data: U.S. Census Bureau, Population Division, Working Paper 38, January 13, 2000, Table F, p. 29.

growth than US00 for the United States, the youth dependency ratio of UN98 falls below that of US00. There is very little difference between the projected elderly dependency ratios of the two projections. Consequently, the total dependency rate of US00 exceeds that of UN98 by a few percentage points.

US00 investigated whether four migration scenarios would greatly affect the U.S. dependency ratios projected for the coming century, holding fertility as assumed in the middle series. The effect of these migration scenarios on U.S. population size, described above, is great. The effect of these migration scenarios on the U.S. youth dependency ratio is negligible: After a dip below 30 percent around 2010, the youth dependency ratio will remain between 32 and 33 percent from 2030 through the end of the twenty-first century, according to all of the migration scenarios (Figure 15). Similarly, regardless of the migration scenarios, the U.S. elderly dependency ratio will rise sharply from 2010 until around 2035 and will gradually increase thereafter (Figure 16). By 2050, the U.S. elderly dependency ratio is projected to rise to 39 percent with zero international migration, and to 30 percent with the highest international migration. This gap between the elderly dependency ratios of the zero and highest migration scenarios persists through the end of the twenty-first century, according to US00. The total dependency ratio, being the sum of the youth and elderly dependency ratios, dips slightly around 2010, rises very abruptly until 2030, and then continues a more gradual upward trend for the remainder of the century (Figure 17).

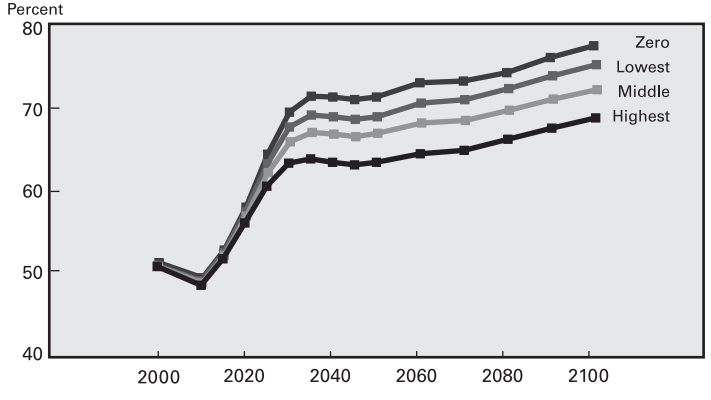
**Figure 16**
**U.S. Elderly Dependency Ratios**
**under Four Migration Scenarios**




Data: U.S. Census Bureau, Population Division, Working Paper 38, January 13, 2000, Table F, p. 29.

*Interpreting the dependency ratios.* The interest in measuring and projecting dependency ratios depends on the assumptions that individuals aged 15 to 64 years represent the potential workers of a population, and that the other individuals represent dependents. These assumptions

**Figure 17**
**U.S. Total Dependency Ratios**
**under Four Migration Scenarios**




Data: U.S. Census Bureau, Population Division, Working Paper 38, January 13, 2000, Table F, p. 29.

are open to challenge (Treas 2000; Seike 2001). In many less developed and some more developed countries, children begin working with or without pay before age 15. In more developed countries where a high fraction of young people pursue secondary and higher education, only a fraction of the population aged 15 to 25 may be available to the labor force. For women, labor force availability during the middle years interacts with levels of fertility, institutions available locally for childcare, and cultural restrictions on the economic activity of women. At the end of the working interval, average ages of retirement have dropped below 65 years in some countries and some individuals continue working far beyond age 65.

How much of an economic burden the elderly population will represent depends substantially on the health of the elderly and on the economic and social institutions available to support their care, to the extent it is needed. The following observations are based on Singer and Manton (1998). Nationally representative longitudinal surveys from 1982 through 1994 of the U.S. population aged 65 and older residing in the community and in institutions indicated that the rate of chronic disability could be declining among the elderly as rapidly as 1.5 percent per year. Many risk factors for chronic diseases have been improving in the United States since 1910, and many of the improvements are linked to education. The proportion of people aged 85 to 89 with fewer than eight years of education is projected to decline from 65 percent in 1980 to 15 percent in 2015. However, the beneficiary projections of the Social Security Administration and the Medicare Trust Fund do not directly represent trends in health, education, or socioeconomic status. Singer and Manton (1998) calculated that a fall of 1.5 percent per year in disability would keep the ratio of economically active persons aged 20 to 64 to the number of chronically disabled persons aged 65 and older above 22:1, the value in 1994 when the Hospital Insurance Trust Fund was in fiscal balance, until 2070. However, this same ratio would fall to 8:1, a level 63 percent below a cash flow balance, if disability rates among the elderly did not change.

These conclusions provide a useful practical warning. Extrapolating directly from dependency ratios to economic burdens can be hazardous. See Lee and Tuljapurkar (in press), Lee (2001), and the paper by Ronald Lee and Ryan Edwards in this volume.

*Sex ratio among the old elderly.* The sex ratio among the elderly changed dramatically in the last half century, according to calculations based on the UN98 estimates and projections (Table 1). In 1950, the ratio of the number of females aged 80 and older to the number of males aged 80 and older in the more developed countries was 1.74. This ratio rose to 2.26 by 2000. In the less developed countries, the same ratio rose from 1.46 in 1950 to 1.57 in 2000. Among the elderly 80 and older everywhere in the world, women outnumber men by more than 50 percent, and in the more developed countries by as much as 2 to 1.

The medium projection of UN98 indicated that by 2050 the ratio would fall in the more developed countries and would increase only slightly in the less developed countries. However, UN98 had information on adult mortality referring to 1994 or later for only about one-third of all countries or areas considered. Another one-third of countries had information obtained before 1975 or no information at all (United Nations 1999c, p. 178). Further, the art of projecting relative mortality improvements by sex has a slim scientific basis at present (see *Mortality assumptions*, below). In the absence of reliable baseline data on mortality and adequate theory for prediction, these projected ratios deserve skepticism. If the present imbalance by sex continues or increases, new social arrangements among the elderly may arise.

## Assumptions of the Projections

Both the UN98 projections and the Census Bureau international (US98) and domestic (US00) projections are standard cohort-component projections. They require two ingredients: (a) reliable data or estimates of the present size and age composition of each population, and (b) scenarios or predictions of future values of age-specific rates of fertility, mortality, and migration, whether international or urban-rural.

Cohort-component projections also require a choice of the boundaries around the population to be analyzed. Both agencies use national populations as the unit of estimation and projection. The practical reason for this choice is that data are most frequently available at the national level. For large countries with substantial local demographic heterogeneity, such as India, China, the United States, and Russia, it might make more demographic sense to project local regions independently and derive national projections by summation, just as global projections are currently derived by summation of national projections.

The assumptions concerning fertility, mortality, and migration underlying UN98 are spelled out in United Nations (1999c, pp. 178-188). The assumptions underlying the Census Bureau's international projections US98 are spelled out in Appendix B of U.S. Census Bureau (1998), which is a summary of Arriaga et al. (1995). The methodological reports of both agencies devoted special sections to describing how the HIV/AIDS epidemic affected mortality projections. Those specialized methods will not be reviewed here. The assumptions underlying the Census Bureau's projections for the United States, US00, are spelled out by Hollmann et al. (2000).

All these are "business as usual" projections, which assume no exceptional surprises. External factors can affect the trajectory of a population only by acting through fertility, mortality, and migration, and demographic attention usually focuses on these three variables and not on the underlying factors that may affect them. The projections assume

implicitly (Cohen 1995, 1999, 2001) that the next century will not be afflicted by a lethal global pandemic of a novel infectious disease, by massively destructive warfare, or by a meteoric impact that darkens the skies for years. They assume no abrupt shift in oceanic circulation or global climate that melts all polar ice, raises the sea level by tens of meters, and ends conventional agriculture (compare O'Neill et al. 2001). All of these catastrophes are conceivable. None is especially unlikely. Demography has little that is useful to say about their consequences.

In the last half century we have learned that such things do happen, however. We have had surprises from persistent pesticides, from the chlorofluorocarbons that were "wonder chemicals," from human concentrations of strontium caused by above-ground tests. We have had biological surprises—AIDS and the West Nile virus. The corn blight knocked out one-third of our corn crop one year, and antibiotic resistance has weakened our ability to treat some bacterial diseases. American power plants spend millions each year to get the zebra mussels out of their filters. Then there are the informational surprises. Nobody anticipated the Y2K problems, or the potentially devastating effect of informational viruses. There are military surprises—the World Trade Center bombing and subsequent destruction, the attacks on the U.S. embassies. And there are the economic surprises: the 1973 oil embargo, the collapse of the former Soviet Union, the Asian financial crises.

There are two sides to the argument. You could say that when we have populations concentrated in cities, we will get new surprises that will be more devastating than we can anticipate. On the other hand, we have been having these surprises for the last century and maybe they are already built into the extrapolations that we make. I will leave the question to others, but I do believe that we have to expect surprises and remember that these projections are "business as usual" projections.

## Major Assumptions of the United Nations Projections

The Population Division of the United Nations prepared cohort-component projections for each of the 184 countries or areas with an estimated population of 150,000 or more in 1995, using 5-year age groups and 5-year time steps, from 1995 to 2050. For the remaining entities with smaller populations, only the total population size was projected. Three main variants (high, medium, and low) were calculated, apart from the "constant-fertility" variant based on the fertility level estimated for 1995.

*Fertility assumptions.* For the medium variant, each country was assigned a target level of fertility and a target quinquennium at which that level would be reached. In countries with a total fertility rate greater than 2.1 children per woman in 1990-95, fertility was assumed to decline smoothly until the target of replacement level (that is, 2.1 children per woman) was reached. Once the target was reached, fertility was assumed

to remain constant at that level until the end of the projection interval in 2045-50. In countries with a total fertility rate between 1.5 and 2.1 children per woman in 1990-95, the target level was 1.9 children per woman. In countries with a total fertility rate less than 1.5 children per woman in 1990-95, the target level of fertility was 1.7 children per woman. Finally, in countries with a total fertility rate of 2.1 or below in 1990-95 for which the completed fertility of the 1962 cohort was available, the target level was the average of that completed fertility and either 1.9 or 1.7 (according to whether the 1990-95 total fertility was above or below 1.5 children per woman). Thus, where recent completed fertility was available for a below-replacement country, information about that level of fertility was used to influence the target level.

For the low variant, in countries with a total fertility rate above 2.1 in 1990-95, the target level was 1.6 children per woman (half a child below replacement). In countries with a total fertility rate at or below replacement in 1990-95, the target level was 0.4 children below the target level for the medium variant or the most recent level recorded, whichever was lower.

For the high variant, in countries with a total fertility rate above 2.1 in 1990-95, the target level was 2.6 children per woman (half a child above replacement). In countries with a total fertility rate at or below replacement in 1990-95, the target level was 0.4 children above the target level used for the medium variant.

These target levels have the virtues of being clear, consistent, and plausible. They have the drawback of being unsupported by theory or historical pattern. No case is yet known of a population with fertility above replacement level that converged to replacement level and then stayed there. There is little evidence to support the assumption that countries with fertility below 1.5 children per woman will increase their fertility to 1.7 children and stay there.

The target quinquennium differed from country to country, but for each country was the same in all three variants. For countries with total fertility above replacement in 1990-95, a target quinquennium was selected by an essentially unrepeatable exercise of judgment (United Nations 1999c, p. 180): "Decisions on which target period to choose were based mainly on the level of fertility obtained by 1990-1995, taking into account recent trends in fertility. In general, the higher the fertility level in 1990-1995, the longer it would take a population to reach the target fertility level." The results of this exercise of judgment were made available in a table (p. 181) and were compared with the judgments made in previous revisions of United Nations projections.

The target quinquennium for countries with total fertility below replacement in 1990-95 was established differently. In these countries, recent data were generally available to permit estimation of a trend in total fertility. This trend was extrapolated to the year 2000, and the value

of the total fertility rate according to that extrapolation was used for the projection for 2000-05. Thereafter total fertility moved toward the target fertility at a rate of 0.07 children per quinquennium until the target level was reached. Then fertility remained constant until the end of the projection. The high and low variants assumed that fertility moved at 0.1 children per quinquennium, starting in 2000-05, until the target level was reached, and then remained constant. A number of minor modifications of these procedures were then added and reported.

Given a total fertility level for each quinquennium, age-specific fertility rates were constructed by separate procedures for countries with fertility above replacement and countries with fertility below replacement. For countries with fertility above replacement, UN98 interpolated between the most recently available age-specific fertility schedule for the country (at the beginning of the projection interval) and a model fertility schedule, which was assumed to hold at and after the target quinquennium. The model fertility schedule was selected to represent early, late, or intermediate childbearing, according to the pattern observed in the country. For countries with fertility below replacement, the shape of the age-specific fertility schedule estimated most recently was held constant throughout the projection.

The high, medium, and low variants assumed that all countries simultaneously experienced high, medium, or low fertility, respectively. No independent fluctuations among countries were included in the projections. Consequently there were no cancellations of high fertility in some regions by low fertility in other regions. In apparent contradiction to this assumption, the historical record shows that fertility levels do not always change in synchrony in all countries.

*Mortality assumptions.* Each country was assigned a trajectory of mortality that was the same for all variant projections. Life expectancy was assumed to rise everywhere except in three classes of countries: thirty-four countries (twenty-nine in Africa, three in Asia, two in Latin America and the Caribbean) with 2 percent or more adult HIV prevalence or with large numbers of HIV-infected people (Brazil and China); countries with recent war or severe civil strife; and formerly Communist countries with recent histories of prolonged mortality stagnation or increase.

In countries where mortality was assumed to decline in the future, a fast, medium, or slow pace of decline was assumed for the interval from 1995 until 2025. After 2025, a medium rate of decline was assumed. The higher the expectation of life at birth was at the start of the projection in 1995, the lower the rate of increase in life expectancy at birth. For example, in the medium schedule of fertility decline, a country starting with a male life expectancy at birth of 55 years would be projected to experience an improvement in life expectancy at birth of 2.5 years per quinquennium, while a country with a male life expectancy at birth of 70

years would be projected to experience an improvement in life expectancy at birth of 1.0 years per quinquennium. For each pace of mortality improvement, female life expectancy rose at the same or a faster rate than male life expectancy. Life expectancies were translated into age-specific survival ratios using model life tables. These life tables converged over time to a single target life table with an expectation of life at birth of 82.5 years for males and 87.5 years for females. No country was expected to achieve these life expectancies by 2050, but Japan came closest.

Like the fertility assumptions of UN98, these assumptions about mortality are clear, consistent, and plausible but are unsupported by theory or universal historical pattern. Whereas it was previously assumed that mortality would only improve, the surprises of the HIV/AIDS epidemic and the collapse of some Communist economies showed otherwise. One may anticipate continuing surprises in the future courses of both mortality and fertility. Future mortality projections may wish to draw on recent results of Tuljapurkar, Li, and Boe (2000).

Whereas all previous United Nations population projections had used 80-plus years as the final age group, UN98 recognized the growing numbers of the oldest old and divided the 80-plus age group into four quinquennial age groups and one final 100-plus age group. This extension required substantial technical innovation, too complex to report here, because for most countries no direct information on mortality at older ages was available.

*International migration assumptions.* UN98 reported candidly (United Nations 1999c, p. 186): "International migration is the component of population dynamics most difficult to project reliably. This occurs in part because the data available on past trends are sparse and partial, and in part because the movement of people across international boundaries, which is a response to rapidly changing economic, geopolitical or security factors, is subject to a great deal of volatility." The demographic significance of future international migration is virtually impossible to assess on a global basis, although international migration is clearly likely to remain important for some identifiable countries, including the United States.

UN98 classified countries into four groups. In the first group, 48 of the 184 countries were assumed to have zero net migration during the projection interval. In the second group of countries with short-term migration only (many of them sending or receiving forced migrants), nonzero net migration was assumed only through 2005 or 2015. This group included half the countries in Latin America, a third of those in Africa, and a fifth of those in Asia. A third group of 62 countries was assumed to experience nonzero net migration until 2020 or 2025. These countries do not have a long migration history or policies that foster immigration or emigration. In the fourth group, 31 countries were assumed to have nonzero net migration until 2050. These countries have a long history of labor migration or migrant workers, either as origin or

destination. This group includes Australia, Canada, New Zealand, and the United States as well as one-fifth of the countries in Africa and Asia. Models were used to distribute the total net number of migrants by age and sex as required for a cohort-component projection, except in a few cases where direct data on age- and sex-distributions of international migrants were available. These distributions were kept constant throughout the projection interval.

### Major Assumptions of the U.S. Census Bureau International Projections

US98 assigned a target level of life expectancy at birth and a target total fertility rate for a target year in the future, determined a linear or logistic trend of these measures between the base year and the target year, and specified an age- and sex-pattern of mortality and a female age-pattern of fertility. This approach completely parallels that of UN98.

In setting target levels for fertility and mortality, US98 fitted a logistic function where estimates were available for more than one date in the past, then used judgment to evaluate the plausibility of the target provided by the logistic function (U.S. Census Bureau 2000, p. B-5): "For example, for mortality, information concerning programs of public health are [is] considered in judging the results. For fertility, factors such as trends in age at marriage, the proportion of women using contraception, the strength of family planning programs, and any foreseen changes in women's educational attainment or in their labor force participation in the modern economic sector are considered." This description is a rare example where the official methodological literature of these demographic agencies explicitly recognized an impact of women's education on the future of population. The evidence for such linkage is substantial (for example, Caldwell 1980; Jejeebhoy 1996; Bledsoe et al. 1999; Lutz, Goujon, and Doblhammer-Reiter 1999; Lloyd, Kaufman, and Hewitt 1999, 2000). However, the quantitative link among the non-demographic, including educational, factors just mentioned and the assumed targets is not made explicit.

In establishing baselines and assumed future trends for international migration, US98 (pp. B-4 to B-6) reported candidly: "most data on international migration are educated guesses at best. . . . Assumptions about future migration are generally much more speculative than assumptions about fertility and mortality. International migration may occur as a result of changing economic conditions, or as a result of political unrest, persecutions, famines, and other extreme conditions in the countries of origin. . . . Due to the unpredictability of conditions such as crop failure, emerging violence, and bellicose activities, migration forecasts are subject to large errors." In general, where migration had a negligible impact on a country's current population growth rate, future migration was assumed to be zero. Where migration was significant for a country, the number of migrants from the recent past was held constant

during the near-term projected future. Projected migration was assumed to diminish to zero in the medium- to long-term future, which was not defined in the report.

**Comparison of United Nations and Census Bureau Projections**

Hollmann, Mulder, and Kallan (2000, pp. B-16 to B-18) reviewed the extent and the origins of the differences between the Census Bureau projections and the United Nations projections. According to their comparison of US98 with the United Nations' 1996 assessment, the maximum difference in the world population between 1950 and 2050 was smaller than 2 percent, or about 130 million people, in 2030. For individual countries in 1990, populations differed by up to 40 percent, and 11 countries differed by 10 percent or more. While the United Nations generated projections for 5-year time steps and quinquennial age groups, the Census Bureau used single years of time and age. While the United Nations published estimates and projections every other year, the Census Bureau has updated its International Data Base at least twice a year and revised its projections once a year. Only the United Nations provided demographic variables for all countries back to 1950.

Apart from the choices of time interval and frequency of revision, the differences between the projections of the two agencies were attributed by Hollmann, Mulder, and Kallan to differences in the availability of country data, differences in the assessment of data quality, differences in estimates based on country data, differences in procedures for projecting fertility, mortality, and international migration, and differences in projection software. National Research Council (2000) provides a more comprehensive comparative analysis of major official projections.

Demographers are currently developing a wider range of demographic projection techniques than these agencies currently use, including techniques for statistically more meaningful assessments of the uncertainty of projections (Alho 1997; Alho and Spencer 1990; Anderson, Tuljapurkar, and Lee 1999; Lee 1999, 2000a, 2000b; Lee and Miller 2000; Lee and Tuljapurkar 1994 and in press; Lutz, Goujon, and Dobbelhammer-Reiter 1999; Lutz, Sanderson, and Scherbov 1997, 2001; Tuljapurkar 2001; Tuljapurkar and Boe 1998; Tuljapurkar, Li, and Boe 2000). The official agencies use some recently developed techniques (such as model life tables, model fertility schedules, and methods of estimation from incomplete data) to supplement the limited demographic data available, but the essential ideas of the projection techniques used are to be found in a paper by the English economist Edwin Cannan (1895), published at the end of the nineteenth century. It is to be hoped that some of the new approaches to population projection developed within the last decade will be incorporated into institutional projection procedures by the end of the twenty-first century.

## References


Ahlburg, Dennis A. and James W. Vaupel. 1990. "Alternative projections of the U.S. population." *Demography* 27(4), pp. 639-52.

Alho, J. 1997. "Scenarios, uncertainty, and conditional forecasts of the world population." *Journal of the Royal Statistical Society* 160, Series A, Part 1, pp. 71-85.

Alho, J. and B. D. Spencer. 1990. "Uncertain population forecasting." *Journal of the American Statistical Association* 80, pp. 306-14.

Anderson, Michael, Shripad Tuljapurkar, and Ronald Lee. 1999. "Chances are. . . Stochastic forecasts of the Social Security trust fund and attempts to save it." March 26, 1999. Follow-up to paper presented to the Social Security Advisory Board forum, Washington, DC, 13 October 1988.

Arriaga, Eduardo E. et al. 1995. *Population Analysis with Microcomputers*. U.S. Bureau of the Census, International Programs Center. Washington, DC.

Bell, Felicitie C. 1997. *Social Security Area Population Projections: 1997*. Actuarial Study No. 112, Social Security Administration, SSA Pub. No. 11-11553. Social Security Administration, Office of the Chief Actuary, Baltimore, MD 21235. URL http://www.ssa.gov/OACT/NOTES/AS112/as112cov.html [accessed 9 August 2001].

Bledsoe, Caroline, John B. Casterline, Jennifer A. Johnson-Kuhn, and John G. Haaga, eds. 1999. *Critical Perspectives on Schooling and Fertility in the Developing World*, Washington, DC: National Academy Press.

Caldwell, John C. 1980. "Mass education as a determinant of the timing of fertility decline." *Population and Development Review* 6(2), pp. 225-55.

Cannan, Edwin. 1895. "The probability of a cessation of the growth of population in England and Wales during the next century." *The Economic Journal* 5(20), pp. 505-15.

Cohen, Joel E. 1995. *How Many People Can the Earth Support?* New York: W.W. Norton.

———. 1999. "Should population projections consider "limiting factors"–and if so, how?" In W. Lutz, James W. Vaupel, and Dennis Ahlburg, eds., *Advances in Population Projections*, pp. 118-38. *Population and Development Review* Suppl. to Vol. 24.

———. 2001. "The future of population." In Richard N. Cooper and Richard Layard, eds., *What the Future Holds: Insights from Social Science*. Cambridge, MA: The MIT Press.

Hiraizumi, Wataru. 2000. "Mass longevity transforms our society." *Proceedings of the American Philosophical Society* 144(4), pp. 361-83, December.

Hirosima, Kiyosi. 1990. "Does very low fertility accelerate nuclearization? Kin availability of low fertility societies." Working Paper Series, No. 8, December, Institute of Population Problems, Tokyo.

Hollmann, Frederick W., Tammany J. Mulder, and Jeffrey E. Kallan. 2000. *Methodology and Assumptions for the Population Projections of United States: 1999 to 2100*. Population Division Working Paper No. 38. Population Projections Branch, Population Division, U.S. Bureau of the Census, Washington, DC. Issued Jan. 13, 2000.

Jejeebhoy, Shireen J. 1996. *Women's Education, Autonomy, and Reproductive Behaviour: Experience from Developing Countries*. New York: Oxford University Press.

Keilman, N. W. 1990. *Uncertainty in National Population Forecasting: Issues, Backgrounds, Analyses, Recommendations*. Berwyn, IL: Swets & Zeitlinger.

———. 1997. "Ex-post errors in official population forecasts in industrialized countries." *Journal of Official Statistics* 13, pp. 245-77.

———. 1998. "How accurate are the UN's world population projections?" *Population and Development Review* 24 (supplement), pp. 15-41.

Keilman, Nico. 2001. "Age structural transitions in historical perspective: What can we learn from the past?" Paper prepared for presentation at the IUSSP/NUPRI Seminar on Population Ageing in the Industrialized Countries: Challenges and Responses, Tokyo, 19-21 March 2001.

Keyfitz N. 1982. "The limits of population forecasting." Chapter 13 in Keyfitz, N., *Population Change and Social Policy*. Cambridge, MA: Abt Books.

Lee, Ronald D. 1990. "Long-run global population forecasts: a critical appraisal." In Kingsley Davis and Mikhail S. Bernstam, eds., *Resources, Environment, and Population: Present Knowledge, Future Options*. Suppl. vol. 16, *Population and Development Review*, 1990, pp. 44-71.

———. 1999. "Probabilistic approaches to population forecasting." In Wolfgang Lutz, James

Vaupel, and Dennis Ahlburg, eds., *Frontiers of Population Forecasting. Population and Development Review* Suppl. to Vol. 24, pp. 156-90.

———. 2000a. "Long-term projections and the US social security system." *Population and Development Review* 26(1), March, pp. 137-43.

———. 2000b. "The Lee-Carter method for forecasting mortality, with various extensions and applications." *North American Actuarial Journal* 4(1), January, pp. 80-93.

———. 2001. "The fiscal impact of population aging." February 5, 2001. //www.demog.berkeley.edu/~rlee/papers/rlee.testimony.pdf

Lee, Ronald D. and Timothy Miller. 2000. "Assessing the performance of the Lee-Carter approach to modeling and forecasting mortality." Paper presented at the pre-PAA Economic Demography meetings in Los Angeles.

Lee, Ronald D. and Shripad Tuljapurkar. 1994. "Stochastic population forecasts for the United States: Beyond high, medium, and low." *Journal of the American Statistical Association* 89(428), December, pp. 1175-89.

———. In press. "Population forecasting for fiscal planning: issues and innovations." In Alan Auerbach and Ronald Lee, eds., *Demography and Fiscal Policy.* Cambridge: Cambridge University Press.

Lloyd, Cynthia B., Carol E. Kaufman, and Paul Hewett. 1999. "The spread of primary schooling in sub-Saharan Africa: Implications for fertility change." Working Paper No. 127, Policy Research Division, Population Council, New York.

———. 2000. "The spread of primary schooling in sub-Saharan Africa: implications for fertility change." *Population and Development Review* 26(3), September, pp. 483-515.

Lutz, Wolfgang, ed. 1996. *The Future Population of the World: What Can We Assume Today?* Rev. ed. International Institute for Applied Systems Analysis, Laxenburg, Austria. London: Earthscan Publications.

———. 2001. "The end of world population growth." *Nature* 412, 2 August, pp. 543-46.

Lutz, Wolfgang, Goujon, Anne, and Doblhammer-Reiter, Gabriele 1999. "Demographic dimensions in forecasting: adding education to age and sex." In W. Lutz, J. W. Vaupel, and D. A. Ahlberg, eds., *Frontiers of Population Forecasting. Population and Development Review* Supplement to Volume 24, pp. 42-58.

Lutz, Wolfgang, Warren C. Sanderson, and Sergei Scherbov. 1997. "Doubling of world population unlikely." *Nature* 387(6635), 19 June, pp. 803-805.

National Research Council. 2000. *Beyond Six Billion: Forecasting the World's Population.* Principal Volume & Appendices (separate volume). Panel on Population Projections, John Bongaarts and Rodolfo A. Bulatao, eds. Committee on Population, Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

O'Neill, Brian C., F. Landis MacKellar, and Wolfgang Lutz. 2001. *Population and Climate Change.* New York: Cambridge University Press.

Population Reference Bureau. 2000. *2000 World Population Data Sheet.* Population Reference Bureau, Washington, DC.

Seike, Atsushi. 2001. "An economic analysis of age discrimination – the impact of mandatory retirement and age limitations in hiring on the utilization of human resources in an aging society." Paper prepared for presentation at the IUSSP/NUPRI Seminar on Population Ageing in the Industrialized Countries: Challenges and Responses, Tokyo, 19-21 March 2001.

Singer, Burton H. and Kenneth G. Manton. 1998. "The effects of health changes on projections of health service needs for the elderly population of the United States." *Proceedings of the National Academy of Sciences* 95, December, pp. 15618-22.

Teitelbaum, Michael S. 2000. "Long-range demographic projections and their implications for the United States." UN/POP/PRA/2000/18. Expert Group Meeting on Policy Responses to Population Ageing and Population Decline, New York, 16-18 October 2000. United Nations Population Division, Department of Economic and Social Affairs, United Nations Secretariat, New York, 28 August 2000.

Treas, Judith. 2000. "Population aging in the United States: retirement, reform, and reality." UN/POP/PRA/2000/18. Expert Group Meeting on Policy Responses to Population Ageing and Population Decline, New York, 16-18 October 2000. United Nations Population Division, Department of Economic and Social Affairs, United Nations, New York, 15 August 2000.

Tuljapurkar, Shripad. 2001. "Risk metrics for the management of social security programs." Paper prepared for presentation at the IUSSP/NUPRI Seminar on Population Ageing in the Industrialized Countries: Challenges and Responses, Tokyo, 19-21 March 2001.

Tuljapurkar, Shripad and Carl Boe. 1998. "Mortality change and forecasting: how much and how little do we know?" *North American Actuarial Journal* 2(4), pp. 13-47.

Tuljapurkar, Shripad, Ronald Lee, and Michael Anderson. 1998. "Effects of changing the Social Security retirement age on the dynamics of the OASDI program." Paper for presentation to the Social Security Advisory Board forum, Washington, DC, 13 October 1988.

Tuljapurkar, Shripad, Nan Li, and Carl Boe. 2000. "A universal pattern of mortality decline in the G7 countries." *Nature* 405, pp. 789-92.

United Nations Population Division. 1997. *World Urbanization Prospects: The 1996 Revision: Estimates and Projections of Urban and Rural Populations and of Urban Agglomerations.* ESA/P/WP.141, December 1997; Annex Tables 1 May 1997. Urban and Rural Areas 1996 [Wall Chart] ST/ESA/SER.A/166. United Nations, New York.

———. 1999a. *World Population Prospects: The 1998 Revision: Volume I: Comprehensive Tables.* ST/ESA/SER.A/177. Department of Economic and Social Affairs, United Nations, New York.

———. 1999b. *World Population Prospects: The 1998 Revision: Volume II: The Sex and Age Distribution of the World Population.* ST/ESA/SER.A/180. Department of Economic and Social Affairs, United Nations, New York.

———. 1999c. *World Population Prospects: The 1998 Revision: Volume III: Analytical Report.* ESA/P/WP.156, 18 November 1999. Department of Economic and Social Affairs, United Nations, New York.

———. 1999d. *Long-range World Population Projections: Based on the 1998 Revision.* ESA/P/WP.153, 27 December 1999. Department of Economic and Social Affairs, United Nations, New York.

———. 2000. *World Urbanization Prospects: The 1999 Revision: Data Tables and Highlights.* ESA/P/WP.161, 27 March 2000. Urban and Rural Areas 1999 [Wall Chart] ST/ESA/SER.A/185. Urban Agglomerations 1999 [Wall Chart] ST/ESA/SER.A/184. United Nations, New York.

———. 2001. *World Population Prospects: The 2000 Revision, Highlights.* ESA/P/WP.165. United Nations, New York.

U.S. Census Bureau. 1998. Report WP/98, *World Population Profile: 1998.* Washington, DC: U.S. Government Printing Office. http://www.census.gov/ipc/prod/wp98/wp98.pdf

———. 2000a. "Annual Projections of the Total Resident Population As of July 1: Middle, Lowest, Highest, and Zero International Migration Series, 1999 to 2100." (NP-T1). Internet Release Date: January 13, 2000. Revised Date: February 14, 2000. http://www.census.gov/population/projections/nation/summary/np-t1.txt

———. 2000b. "Total midyear population for the world: 1950-2050." U.S. Census Bureau, International Data Base. Data updated 5/10/2000. http://www.census.gov/ipc/www/worldpop.htm. Accessed 1 June 2001.

World Bank. 2000. *Global Economic Prospects and the Developing Countries 2000.* Washington, DC: World Bank.