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World Population Futures

by Brian O'Neill and Deborah Balk

Aging, HIV/AIDS, and environmental concerns draw increased attention to population projections.

Fertility trends are key to projections of future world population.

New methods help communicate the uncertainty of projections.

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World Population Futures

by Brian O'Neill and Deborah Balk

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The size and characteristics of the world's future population will depend primarily on how many children women have—but this individual behavior will be influenced by future socioeconomic, political, health, and environmental trends.

What will the future inhabitants of the world be like? How many will there be, and what kind of world will they live in? We can only speculate about the answers to these questions, but we can be reasonably sure that population characteristics and social and environmental factors are likely to become more interconnected. Global environmental changes, for example, will be driven in part by the evolving size, geographic distribution, and makeup of the world's population. In turn, changes in societies, economic systems, and the environment will influence population dynamics.

The nature of these linkages is unclear. Scientists do not agree on how (and how much) demographics, in concert with social, economic, and cultural forces, affect the environment; and they cannot know precisely how much socioeconomic and environmental factors will sway individuals' future decisions about when or whether to have children, practice good health, or move to a new country. Yet the fact that forecasts of future population dynamics are inherently uncertain does not make them any less important. Scientists and policymakers are turning more attention to population projections. Their interest is driven by concern about the potential effects of aging populations on social security systems and economic growth, the possibility of declining populations in some industrialized countries, the long-term consequences of HIV/AIDS, and the implications of demographic trends for long-term environmental changes such as global warming and loss of biodiversity.

At the same time, researchers have taken a renewed interest in the mechanics of population projections, not only to improve accuracy, but also to make the results more useful and the methodology easier to understand for experts in a variety of academic fields and policy arenas. Demographers are experimenting with creative ways to express the uncertainty inherent in all projections and with new approaches for projecting population size and other characteristics. With a growing wealth of census and survey data and medical studies from around the world, researchers are also refining theories about how reproductive behavior and childbearing preferences may change, and on likely improvements in life expectancy.

This *Population Bulletin* explains projection methodology and discusses various approaches for expressing uncertainty. It analyzes the key assumptions on which most global projections are based: baseline demographic data and trends in future fertility, mortality, and migration. The *Bulletin* also reviews the conceptual basis for projecting demographic variables, discusses the extent to which environmental factors are or should be taken into account, and compares assumptions made by different institutions. It concludes with a discussion of what global population projections imply about the kind of world our descendents will inhabit.

Projecting Populations

The population of the world (or of any geographic area) can be projected into the future based on current knowledge about population size and age structure, rates of birth, death, and migration, and assumptions about how quickly these rates will change. The projection results, or output, may involve very different geographic areas, time horizons, or population characteristics, and they may be targeted for a number of different uses. For global or national populations, a time horizon of less than 15 years might be considered short-term; 15 to 50 years, medium-term; and more than 50 years could be considered a long-range projection.[1] The accuracy, geographic coverage, and population characteristics typically vary depending on whether the projections are short-, medium-, or long-term.

Spatial dimensions can range from local areas like counties or cities to the entire world. Local-area projections tend to use shorter time horizons, often less than 10 years, whereas national and global projections can extend decades into the future, and in some cases, for more than a century. Short- and medium-term projections are more likely than long-term projections to include more than the number and age and sex profile of the future population. They may project such socioeconomic characteristics as educational and labor force composition, ethnicity, urban residence, or household type.[2]

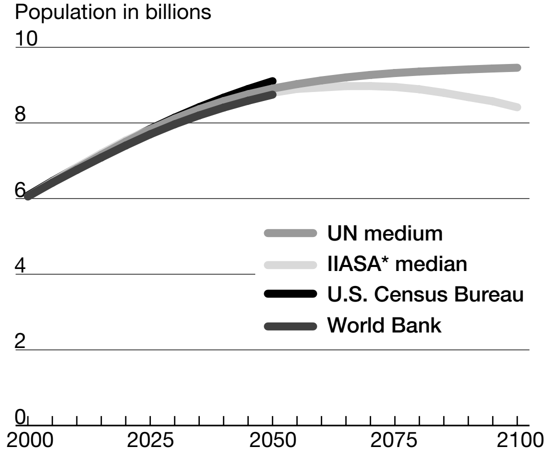
The intended user of the projection results, or output, usually determines the level of detail and time horizon. Businesses often use projections for marketing research; they generally want a single most likely forecast of population classified by such socioeconomic categories as income and consumption habits (in addition to age and sex) and by place of residence. Government planners may be concerned with population aging and its potential social and economic impact. They might want, for example, longer-term projections of the likely health status and living arrangements of the elderly.

Governments and the public policy community, including advocacy groups, often are more interested in a range of likely scenarios that reflect the potential influence of a policy rather than a single "best guess" of future population size. Those concerned with the environmental effects of population growth, for example, may be interested in how policies to reduce fertility might affect future population size. In addition, they may want to study how environmental change might affect demographic change, and vice versa. Rapid population growth might promote overuse of agricultural land, for example, which would deplete resources, and in turn, encourage migration out of the area, which would slow population growth. Researchers studying global environmental changes often use population projections as a variable in models that predict energy consumption, food supply, and global warming.[3] These studies usually require projections with long time horizons (a century or longer) and several scenarios rather than a single most likely projection.

Demographers often are uncomfortable making projections more than a few decades into the future, when most of the population will be made up of people not yet born. Nonetheless, long-term global projections are increasingly in demand by global change researchers.

While individual researchers and institutions have made significant contributions to the methods used to project population, especially at the national level (or below), global projections have been the province of relatively few institutions: the United Nations (UN), the U.S. Census Bureau, the World Bank, and the International Institute for Applied Systems Analysis (IIASA), based in Austria. They use different methodologies, make varying assumptions about future fertility, mortality, and migration trends, and begin with slightly different estimates of current population size. Their results tend to fall within a relatively small band for the next 50 years, then diverge as the time horizon lengthens (see Figure 1).

Figure 1
World Population Projections to 2050 and 2100: The United Nations, World Bank, U.S. Census Bureau, and IIASA



*International Institute for Applied Systems Analysis.

Sources: United Nations, *Long-Range World Population Projections Based on the 1998 Revision* (1999); U.S. Census Bureau, International Data Base, accessed online at: www.census.gov/ipc/www, July 10, 2001; The World Bank, World Development Indicators 2001 CD-ROM; W. Lutz, W. Sanderson, and S. Scherbov, *Nature* (Aug. 2, 2001): 543-46; and unpublished data from IIASA.

Global Projection Series

The UN assumed the leadership role in the production of projections and the dissemination of their results beginning in the 1950s, long before the U.S. Census Bureau, the World Bank, and IIASA began to produce global projections. Between 1951 and 2001, the UN produced 17 sets of estimates and projections covering all countries and areas of the world. Until 1978, the UN published new revisions approximately every five years; since then, it has published revisions every two years. These medium-term projections, published in the UN's *World Population Prospects* series, include various scenarios with different assumptions about future birth rates and, more recently, include alternative scenarios for average life expectancy and migration.

The UN projections are available in print, online through the UN website, and on CD-ROM, and they are the most widely cited throughout the world. UN projections are used for planning by individual governments and by the UN and other international agencies, as well as by the media, academics, and research institutions.

The World Bank was the second major institution to produce country and global population projections. The World Bank first published country-level population projections in the annual *World Development Report* in 1978, although they prepared earlier projections for internal use. The World Bank projections did not extend as far into the future as did the UN series, but they did identify the year in which each country's population was projected to stop growing. Later editions of the *World*

Development Report contained population projections to 2000 and 2025. About every two years between 1984 and 1995, the World Bank produced long-term projections of world population out to 2150.[4] While the World Bank no longer publishes long-term projections, it continues to create projections for use in projects and planning within the World Bank, for example, to anticipate the demand for pensions, education resources, and health care. Since 1997, the World Bank has included medium-term projections of country populations, which are updated annually and available on their *World Development Indicators* CD-ROM.

Assumptions used to project population are based on expert opinion.

The U.S. Census Bureau has been compiling and evaluating international population statistics since the 1950s, primarily by assisting the statistical offices in less developed countries and by preparing estimates of population and vital rates. The Census Bureau has published projections for all countries and for world regions in the *World Population Profile* since 1985.[5] The Census Bureau publishes projections prepared under one set of assumptions, and prints the results for 15 to 25 years into the future. *World Population Profile: 1998* includes projection results for countries and regions through 2025. Projections through 2050 are offered in an online service that is updated more often. The Census Bureau projections are used by other U.S. government agencies to help manage and design foreign assistance programs, and for long-range planning and other uses, as well as by national governments and nongovernmental organizations around the world.

The Population Project at IIASA first produced a set of long-range global population projections in 1994 and updated them in 1996 and 2001.[6] IIASA projections are made for 13 regions of the world through 2100. The earlier projections used three scenarios of fertility, mortality, and migration, which yield a possible 27 output scenarios. Additional projection series can be created by combining different migration scenarios with different scenarios for fertility and mortality in each region.

How Are Populations Projected?

The population of a geographic area grows or declines through the interaction of just three variables: fertility, mortality, and migration. To project the size of a population at a future date, demographers generally make an assumption about levels of fertility and mortality and about how many people will move in or out of the area during the projection period. The net population increase or decrease over the period (derived from the number of births and in-migrants minus the number of deaths and out-migrants) is added to the baseline population to project the future population size.

Nearly all national and global population projections are produced from assumptions about these three demographic variables using some variant of the cohort-component method.[7] Under the cohort-component method, an initial population for a country or region is grouped into cohorts defined by age and sex. Women ages 15 to 19 in 2000 would make up one cohort of the population, for example. Each cohort is projected forward according to assumed migration and mortality rates for that age and sex group. The U.S. Census Bureau estimates that in the year 2000, for example, there were 9,672,000 females ages 15 to 19 residing in the United States. The Census Bureau projects that by the year 2005, when members of this cohort will be ages 20 to 24, the cohort will have grown by 230,000 to number 9,902,000 (see Figure 2). This cohort will lose about 115,000 women from deaths over the period, while it gains about 345,000 women from international migration (the Census Bureau projects that 345,000 more women in this age group will move into the United States than will move out between 2001 and 2005). Similar calculations are made for each age group and for both sexes.

New cohorts are added at the bottom of the age structure by births over the projection period. The number of births is projected by applying assumed birth rates to the base population. The Census Bureau further divides the U.S. population by racial and ethnic group—so that each cohort is defined by age, sex, and race or ethnicity. The Census Bureau assumes slightly different fertility, mortality, and migration rates for each racial and ethnic group.

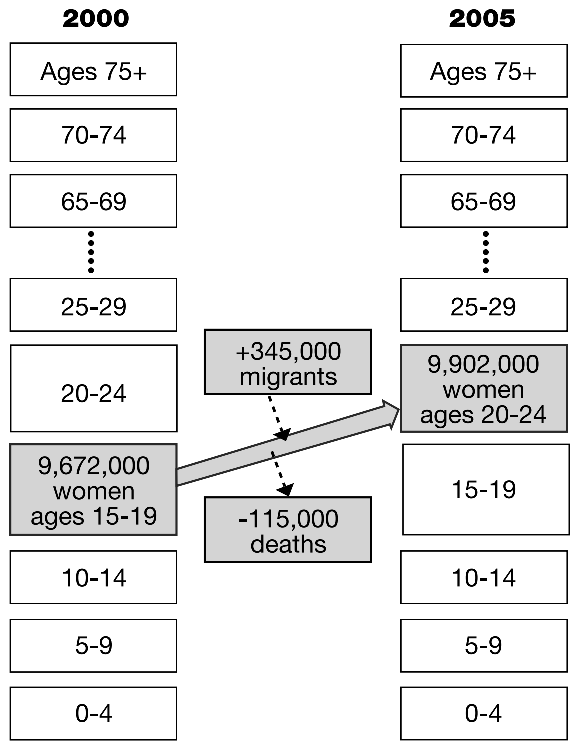
The cohort-component method was the major innovation in the evolution of projection methodology. It was first proposed by the English economist Edwin Cannan in 1895, and was then reintroduced by demographer Pascal Whelpton in the 1930s, formalized in mathematical terms by P.H. Leslie in the 1940s, and first used to produce a global population projection by demographer Frank Notestein in 1945.[8] Since Notestein's 1945 projection, the cohort-component method has become the dominant means of projecting population. It has remained essentially unchanged, but it has been extended by incorporating population characteristics such as region of residence or educational status (multistate projections) and by innovations in ways to demonstrate the uncertainty in projection results.[9]

The cohort-component model is nothing more than a particularly useful accounting scheme: It works out the inevitable consequences of the size and age structure of the population at the beginning of the period and the fertility, mortality, and migration rates assumed to prevail over the projection period. The real work in producing projections lies not in refining the mechanics of the model itself, but in estimating the population size and age structure in the base period and in forecasting future trends in fertility, mortality, and migration.

Although approaches may differ, the assumptions used to produce global population projections are based on expert opinion informed by current conditions, past trends, and theories about why and how much fertility, mortality, and migration are likely to change. Demographers draw on specialized knowledge about the components of population change to develop the assumptions used in projections.

Figure 2

Projecting a Cohort of U.S. Women Ages 15–19 in 2000 to 2005: The Cohort-Component Method



Source: Data from U.S. Census Bureau. Adapted from J. Cohen, *How Many People Can the Earth Support?* (1995): figure 7.2.

Baseline Data

Population projections must begin with an estimate of the baseline data: the number of people in each age and sex cohort of the population at the beginning of the projection period. The primary sources of baseline data are national population censuses, which are carried out about once a decade in most countries of the world.

Box 1

Accuracy of Population Projections

Projections from the United Nations (UN) and the World Bank have become more accurate over time, as measured by their ability to forecast the population for 2000. UN projections of the world population size in 2000 made in the early 1970s were off by 6 percent to 7 percent, while projections made in the 1990s were off by less than 1 percent. But most of this improvement in projection accuracy reflects the fact that more recent projections had less time to go wrong before 2000. When comparing projections with equal time horizons—10 years into future, for example—there is little evidence of improvement.

Projections of population size tend to be more uncertain, or less accurate, under particular circumstances.[1] They are less accurate (1) for less developed countries than for more developed countries, partly because less developed countries tend to have limited and less reliable data; (2) for smaller countries than larger ones, perhaps stemming from the greater attention devoted to larger countries; (3) in younger and older age groups than in middle age groups because incorrect assumptions about fertility and mortality have a greater effect at older and younger ages; and (4) at the country level than at regional or global levels because errors at the country level partly cancel each other when aggregated to regions or to the world. Countries are more susceptible to errors from migration assumptions, and regions are more influenced by larger countries, for which projections tend to be more accurate.

Projecting vital rates has also proved to be difficult. UN projections of fertility rates have consistently been too high for most regions of the world. In Latin America, for example, the estimates of fertility rates at the start of the projection period often were too high, which contributed to excessively high projections of future fertility rates. In addition, most projections by the UN and other organizations anticipated a halt to declines in fertility, while in many countries fertility continued to fall well below replacement level.

The UN has generally been too pessimistic about increases in life expectancy. Projections for North America in the 1970s failed to foresee the persistent rise in life expectancy above 70 years. A lack of accurate base period or baseline data also contributes to inaccuracy in the projected life expectancy in many countries. Projections for India in 1975 and 1980, for example, underestimated life expectancies by several years because baseline estimates were too low. The forecasts of life expectancy in Africa are an exception—they consistently have been too optimistic, missing especially the flattening in life expectancy after 1985, in part because of HIV/AIDS.

UN projections of urban population growth in less developed countries have also generally been too high.[2] The most recent projections, made in 1999, foresaw an urban population in 2000 that is 9 percent smaller than the UN had projected in 1980. This difference is not caused primarily by slower than expected growth of total population—projections of total population have been revised by only 2 percent over the same period—but rather to overestimating the rate of urbanization itself. The reasons for a slower than expected growth of urban population in less developed countries are not clear, but evidence suggests that weak expansion of urban industries, population aging, and policies affecting population distribution may have played a role.

Although analysis of past errors can provide insight into the projection process, success or failure in projecting population under one set of conditions does not necessarily imply continued success or failure under a different set of conditions in the future. In addition, as would be expected, errors grow with the duration of the projection. Thus the performance of past projections a few decades into the future becomes less relevant as the projection horizon stretches to 100 years or more.

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1. John Bongaarts and Rodolfo A. Bulatao, eds., *Beyond Six Billion: Forecasting the World's Population* (Washington, DC: National Academy Press, 2000).
2. Martin P. Brockerhoff, "Urban Growth in Developing Countries: A Review of Projections and Predictions," *Population and Development Review* 25, no. 4 (2000): 757-78.

In more developed countries, census results tend to be complete and provide a solid base for making projections (see Box 1). Fertility and mortality rates are calculated from recorded birth and death statistics and population estimates based on censuses. This information allows demographers to produce a relatively consistent picture of historical population change. Even in these countries, however, international migration statistics are incomplete, and net migration is often estimated from the differences between birth and death rates and assumed population change.[10]

Estimating the base population and vital rates for less developed countries is more difficult because demographic data are incomplete and often inaccurate. Over the past 20 years, however, data collection efforts have increased substantially around the world. When the UN produced its 1998 revision of *World Population Prospects,* 83 percent of all countries or areas had post-1985 census data available on population size and age structure.

Vital rates for many less developed countries are derived from surveys and are less accurate than rates based on the complete birth and death records that are available in more developed countries. Information on adult mortality is usually the least complete—births and child deaths are more likely to be recorded. Countries accounting for 40 percent of global population in 1998 lacked any recent data on adult mortality, which makes it difficult to estimate baseline population size and the age and sex structure of the population as well as to estimate mortality trends.

The UN Population Division produces the most widely used estimates of population size, age structure, and vital statistics (birth and death rates). Obtaining and evaluating data make up the bulk of the Population Division's demographic work. UN demographers use statistical techniques to, for example, make sure that estimates of vital rates are consistent with estimates of population size and age structure. A history of high fertility rates would be consistent with a young age structure, while a history of low fertility would be associated with an older age profile.

The Census Bureau and World Bank make their own estimates of baseline data. While the UN and both of these other organizations rely on the same data sources and use similar techniques for estimating demographic variables, they may employ different assumptions about census undercounts and vital rates, and they may obtain and incorporate new data sources at different times. The Census Bureau might use a lower fertility rate for Brazil than the UN, for example, because it adopted the results of a new demographic survey before UN demographers had a chance to evaluate and incorporate the results.

In practice, these differences have been very small at the global level. Estimates of the 1990 world population from the Census Bureau and the UN 1998 series differed by less than 0.1 percent. For individual countries, differences can be larger: In 11 countries the differences in population size estimates were 10 percent or more.

In its most recent projections, IIASA used baseline data on population size, total fertility rates, and life expectancies from the UN 1998 revision and the U.S. Census Bureau.

Uncertainty

Projections of the size and characteristics of a population at some future date are based on assumptions drawn from past trends and current theories. Because the future is unknown, a projection based on the past is likely to be wrong—the burning question is: by how much? This is a crucial question for those who use population projections, for example, to meet future educational, energy, or pension needs. There is no generally accepted approach to characterizing the uncertainty inherent in all population projections, but demographers are developing more sophisticated ways to do this.

A projection based on the past is likely to be wrong—the question is, by how much?

Approaches to characterizing uncertainty can be grouped into two main categories: scenarios, used in UN global projections and in many national projections (see Box 2), and probabilistic projections, used by IIASA (see Box 3, page 12).

Projecting Fertility

Fertility has the greatest effect on population growth because of its multiplier effect: Children born today will have children in the future, and so on. The fertility component of popu-

Box 2

Using Scenarios to Show Uncertainty

Population projections according to alternative scenarios, called variants in some cases, show what the future population would be if fertility, mortality, and migration follows various paths. Some scenarios or variants are purely hypothetical—such as the United Nations (UN) constant fertility variant, which projects world population assuming that fertility levels hold their same level. The UN demographers do not consider this likely, but it illustrates what would happen if fertility does not decline at all. The world population would reach 53 billion by 2100, under the UN constant fertility assumption, about six times higher than projected in the medium scenario.

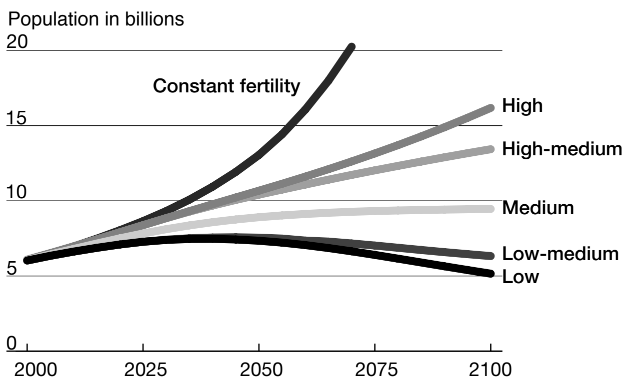
Other scenarios offer users a choice of more plausible projections that they can employ in their own analyses. Users of population projections sometimes require projections that conform to various "storylines." Population projections might form just part of a scenario of future energy use and greenhouse gas emissions that presuppose particular socioeconomic, technological, or political developments.[1]

The scenario approach also has several weaknesses. The most important is that users cannot interpret the probability that population will track a higher or lower scenario. The only difference between the high and low scenarios in the UN long-range projections, for example, is the fertility rate (see figure). The UN assumed an average of 2.03 children per woman after 2050 for its medium scenario, and assigned rates about one-half birth higher and lower, respectively, for the high and low scenarios. The UN provides little information about the likelihood of a particular scenario, except that it suggests that both the high and low scenarios are "unsustainable over the very long run."[2] These scenarios produce a global population that doubles or is halved every 77 years. Theoretically, they and would eventually lead to extinction or to implausible crowding. The UN produces intermediate scenarios with more moderate rates of growth or decline and concludes that future demographic rates "will very likely be bound by these (intermediate) scenarios if sustainability is to be maintained."

UN World Population Projections, 2000–2100

Assumed fertility rate (TFR) 2050–2100

Projection series	TFR (Average children per woman)
High	2.51
Medium	2.03
Low	1.56
Constant	4.18-4.78



Note: TFR (total fertility rate) is the average total number of children that would be born to a woman given current birth rates. These TFRs for the world are derived from the values assumed for geographic regions.

The TFR values for the high-medium and low-medium scenarios are between the high and medium, and medium and low values, respectively. The constant fertility scenario derives from holding constant the TFRs estimated for each region in 1995-2000.

Source: United Nations, *Long-Range World Population Projections: Based on the 1998 Revision* (1999).

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2. United Nations, *Long-Range World Population Projections: Based on the 1998 Revision* ESA/P/WP.153 (New York: United Nations, 1999): xiii.

lation projections is summarized by the total fertility rate (TFR), which estimates the average total number of children a woman will have assuming that current age-specific birth rates remain the same throughout her childbearing years.

In general, the projection of the TFR reflects an assumption that fertility will eventually stabilize at a specific level in a country or region and the assumed path the TFR will follow to that level. Once fertility reaches this level, assuming mortality and migration rates remain the same, the population age structure will eventually stabilize as well. The population size will change at constant rate. If there is no net migration (the number of in-migrants is cancelled out by the number of out-migrants), and the TFR stabilizes at replacement level (a little more than two children per woman, the TFR at which the childbearing generation would have just enough children to exactly replace itself), the growth rate will eventually be zero. Both the projected pace of fertility decline and the assumed eventual fertility level are important to determining trends in population size and age structure. The two factors also interact: The lower the assumed eventual fertility level, the more important the pace of fertility decline becomes to projected population size.[11]

Demographic Transition Theory

For countries currently above replacement level fertility, demographic transition theory provides the theoretical basis for forecasting fertility trends. The concept of demographic transition is a generalization of events observed over the past two centuries in the more developed countries. While different societies experienced the transition in different ways, in general, these societies have gradually shifted from small, slowly growing populations with high mortality and high fertility to larger, slowly growing populations with low mortality and low fertility.[12] During the transition

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Policies that enhance opportunities for women outside the home are assumed to also favor fertility decline and ultimately slow population growth.

itself, population growth accelerates because the decline in death rates precedes the decline in birth rates, creating a sudden “surplus” of births over deaths.

Evidence from all parts of the world overwhelmingly confirms the relevance of the demographic transition to today’s less developed countries. The transition is well-advanced in all less developed countries, except in sub-Saharan Africa, where the beginnings of a fertility decline are becoming apparent.[13] Fertility is already below replacement level in several less developed countries, including China, Taiwan, and South Korea. In many other countries in Southeast Asia and Latin America, fertility has fallen to levels seen in the more developed world just a few decades ago.

The biggest difference between the transition in more developed countries and less developed countries has been the speed of the mortality and fertility decline. In Europe, North America, and Japan, mortality fell slowly for two centuries as food supply stabilized, and housing, sanitation, and health care improved. In contrast, mortality in most less developed countries fell over the course of just a few decades after World War II as Western medical and public health technology and practice spread to these regions. Populations are growing much faster in less developed countries than they did in more developed countries at a comparable stage of the demographic transition.

Demographic transition theory has been and continues to be a guiding principle in the study of fertility in less developed countries.[14] Demographers have developed many arguments about why fertility has declined in the past and what might drive further declines in the future. While

Demographic transition theory continues to guide the study of fertility.

Box 3

Using Probabilities to Account for Uncertainty

One way to communicate the uncertainty in population projection results is to derive probability distributions for the projected size and characteristics of a population by using a range of different fertility, mortality, and migration rates. There have been three main bases for determining the probabilities associated with vital rates: expert opinion, statistical analysis, and analysis of errors in past projections.

Expert Opinion

Researchers at the International Institute for Applied Systems Analysis (IIASA) pioneered a methodology for assessing uncertainty in population projections based on asking a group of experts to give a likely range for future fertility, mortality, and migration rates—that is, the vital rates for a given date would be within the specified range 90 percent of the time, or have a 90-percent confidence interval.[1]

IIASA demographers argue that a strength of the method is that it may be possible to capture socioeconomic changes and unexpected events that experts might take into account but that other approaches might miss because they are guided by past events. In addition, this approach may be the best way to estimate probabilities for future demographic measures in geographic areas where data on historical trends are sparse.

The expert opinion approach has several drawbacks—for example, the task of deciding who constitutes an expert will always be problematic, and research has shown that experts tend to be too conservative in their expectations for future changes, on average. Demographer Ronald Lee questions whether experts can meaningfully distinguish between different confidence levels they may place on estimates of future vital rates.[2] He also argues that the method excludes the possibility of fluctuations in vital rates that deviate from a general trend, which could underestimate uncertainty in outcomes. For example, the first probabilistic projections based on expert opinion did not include any scenarios in which fertility starts out high, but ends up low, nor any scenarios with baby booms or busts.

Statistical Methods

Statistical analysis of historical time series data can be used either to project population size directly or to generate probability distributions for population size or vital rates. Lee argues that, unlike methods based on expert opinion, these methods are capable of producing internally consistent probability distributions. While statistical methods also employ expert judgment, they do not rely on it as much as the expert-based method used in the IIASA projections.

Statistical analysis methods have been applied to some national projections but not to global projections.[3] They may be a source of further innovation in long-term global projections.

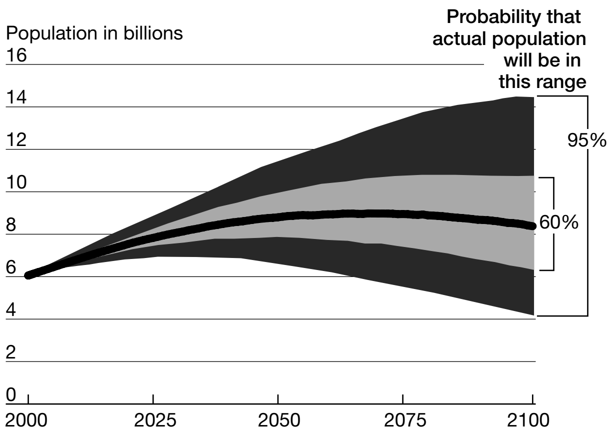
Historical Error Analysis

Population projections made in the past can be evaluated for how well they forecast the actual population, and these errors—the difference between the projected and actual population size—can be used to calculate probability distributions for new projections. A recent report by the U.S. National Research Council (NRC) calculated probability distributions from the errors of UN medium scenario projections for 2000 that were made between 1957 and 1998. The NRC found the each offers important insights, no single, simple theory explains the multifaceted history of demographic transition around the world (see Box 4, page 14). Each explanation suffers from its own shortcomings, and for each, exceptions can be found. It is probably best to think of fertility and mortality transitions as being driven by a combination of factors rather than a single cause, but determining the precise mix of factors at work in a particular population at a given time remains an elusive goal.[15]

The fact that the demographic transition has occurred under so

UN was somewhat more likely to overestimate than to underestimate future population size at the world level, although the size of the error was small. Errors were much greater for projections of country populations, but these errors tended to cancel out over the long term at the national level. The average error in UN projections for individual countries varied from 4.8 percent for five-year projections to 17 percent error in 30-year projections, according to the NRC report. But the report states, "a statistical review of past accuracy is … an imperfect guide to future accuracy."[4]

IIASA Projections of World Population, 2000–2100



Source: W. Lutz, W. Sanderson, and S. Scherbov, *Nature* 412 (Aug. 2, 2001): 543-46. Data provided by IIASA.

These three methods of producing probabilistic projections are not mutually exclusive. The most recent projections from IIASA combine all three elements: Expert opinion is used to define a central path for fertility, mortality, and migration in all world regions. It is also used, in conjunction with historical errors, to define the uncertainty ranges for these values. Time series methods are used to generate paths for each variable that can show realistic fluctuations over time.

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many different conditions and has been driven by multiple causes complicates the study of demographic history, but it also lends support to the idea that a transition to lower fertility is inevitable—which simplifies the task of preparing population projections. Presumably, demographers need not focus on whether a country's fertility will fall from very high levels, but rather on when, how fast, and to what eventual level.

Researchers struggle to discern which social or economic factors drive fertility decline.

Box 4

Explaining Fertility Decline

The earliest attempts to explain the demographic transition cited industrialization and urbanization as the ultimate driving forces.[1] According to this "classical" transition theory, economic modernization leads to improvements in health and nutrition that decrease mortality. Modernization also drives changes in economic and social conditions that make children costly to raise and reduce the benefits of large families. Eventually, this leads to lower fertility. Fertility decline lags mortality decline because cultural norms regarding reproduction are difficult to change while improvements in mortality meet little resistance.

The idea that reduced demand for children drives fertility decline gained theoretical rigor in the 1960s with the development of a theory based on changes in determinants of parents' demand for children. Economist Gary Becker and several collaborators proposed a microeconomic model that described choices parents are assumed to make between numbers of children and consumption of material goods at the household level.[2] The model assumes that fertility falls because, as economic development proceeds, parents' preferences shift toward higher "quality" children requiring greater investments in education and health, while increases in women's labor force participation and wages increase the opportunity costs of raising children. At the same time, development leads to a decline in some of the economic benefits parents may derive from children, such as household labor, income, and old-age security. Thus, as the net cost of children rises, demand falls.

This framework has been extended and made more flexible by taking into account sociological aspects. In the 1970s, economist Richard Easterlin added the influence of economic development on environmental and cultural factors that affect "natural" fertility (what fertility would be in the absence of regulation) and on the costs (including the psychological, social, and monetary costs) of fertility regulation.[3] He proposed, for example, that development may influence fecundity (the physiological ability to bear children) or taboos on intercourse while mothers are breastfeeding, which could lead to an initial rise in fertility as the demographic transition began. In contrast, effects of development on attitudes toward fertility regulation and the time and money required to learn family planning techniques would tend to hasten the transition.

In the 1980s, researchers continued to struggle to discern which social or economic factors are the most important causes of fertility change. Some explanations have given much more weight to sociological over economic factors. Sociologist Norman Ryder argued, for example, that reproductive decisions are not based strictly on a rational weighting of the consequences of childbearing, but are strongly influenced by cultural and normative contexts.[4] Another sociologist and demographer, Jack Caldwell, elaborated a theory that identified a shift away from extended family structures toward the child-centered nuclear family as the cause of a reversal in the flow of wealth (money, goods, and services) from children to parents typical in pretransition societies to the flow of wealth from parents to children typical in transition societies.[5] As children displace parents as beneficiaries of the family, fertility falls.

The shift in family structure could be triggered by economic changes, but also by the spread of new ideas. In a rural agricultural village, for example, a child may provide benefits to the par-

Policies and Fertility Decline

The role of population policies in the decline of fertility in less developed countries over the past several decades, and by extension policy's potential role in determining future fertility levels, is a matter of spirited debate. Family planning programs have been a primary policy tool in the past;[16] there are two main points of view on their effectiveness.

ents through labor that outweigh the cost of having the child. The cultural norms of the community may justify this relationship, a situation that will tend to perpetuate high fertility. If cultural changes erode the social support for relying on children for labor, or if economic development diminishes the importance of labor-intensive agriculture, the benefits of children may no longer outweigh their costs, removing the obstacle to fertility decline.

Other researchers have emphasized the role of cultural over socioeconomic factors. Based on analyses of the fertility transition in Western Europe in the 19th and early 20th century, demographer Ron Lesthaeghe argued that differences in fertility across societies arose largely from differences in religious beliefs and the degree of secularism, materialism, and individualism.[6] He proposed that cultural shifts leading to greater individual control over life goals and the means of achieving them typically led to reduced fertility. Greater individualism was often associated with a decline in religious beliefs and a growth in materialist values.

In work published in the late 1980s, demographers John Cleland and Chris Wilson concluded that ideational change in general, and the spread of new ideas about the feasibility and acceptability of birth control in particular, was a key driver in fertility decline and likely more important than changes in economic conditions.[7] More recently, demographers John Bongaarts and Susan Watkins demonstrated that diffusion of ideas and information about limiting fertility is important.[8] They showed that fertility transitions typically start in leader countries where development levels are relatively high, and then spread to other countries in the region, often before the countries have achieved the same level of development.

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Proponents argue that programs have had a substantial effect on fertility primarily by reducing "unwanted fertility"—births that occur after a woman has had as many children as she wants.[17] The conventional justification for using family planning programs to reduce unwanted fertility is survey data that indicate that many women who want to avoid pregnancy do not use contraception. Family planning programs, therefore, help meet this "unmet need" for contraception by helping couples overcome obstacles to contraceptive use. Obstacles can include limited access to family planning supplies and services, lack of knowledge about contraceptives, fear of side effects from specific methods, disapproval by relatives and others, and the cost of obtaining contraceptive supplies.[18]

In contrast, economist Lant Pritchett has argued that unmet need is much smaller than commonly assumed, and that fertility decline is driven primarily by a decline in the number of children women actually want (desired fertility) rather than a reduction in unwanted fertility.[19] His conclusion is based on the high correlation between desired fertility and actual fertility (the number of children women want compared with the number they have), and the lack of correlation between actual and unwanted fertility. Pritchett argues that because low-fertility countries have low desired fertility, but do not have especially low unwanted fertility, the fertility decline must have been driven by reductions in desired fertility, not by reduced unwanted childbearing. He also argues that family planning programs have had little effect on fertility.

Demographer John Bongaarts concludes that neither view is fully accurate.[20] He agrees that there is substantial unmet need for contraception, but posits that the unmet need is less important to fertility decline than many family planning advocates estimate. Family planning advocates tend to include women who want to use family planning to delay rather than prevent their next pregnancy in their estimates of unmet need. Meeting the family planning needs of these women will not reduce overall fertility as much as family planning aimed at women who want to avoid any more pregnancies. Bongaarts concludes, however, that family planning programs historically have had a substantial effect on fertility. He attributes an estimated 43 percent of the fertility decline between the early 1960s and late 1980s to program interventions.

Future change in fertility may also be affected by public policies that address such social and economic factors as women's status, educational and employment opportunities, and public health. Such policies are receiving increased attention internationally. At the 1994 International Conference on Population and Development (ICPD) in Cairo, 179 countries agreed to a Program of Action that marked a fundamental shift in population-related policies away from demographic targets and toward a new focus on individual well-being. The Cairo program set a number of goals for 2015 that reflected this perspective. Among the goals were universal access to comprehensive reproductive health services (including, but not limited to, family planning); reductions in infant, child, and maternal mortality; and universal access to primary education, with an emphasis on closing the "gender gap" in education, health, and political participation.[21] Although these goals are not primarily motivated by their potential effect on demographic trends, achieving them would likely lead to lower fertility (and lower mortality). Bongaarts estimated, for example, that eliminating unwanted fertility in less developed countries would reduce population in 2100 by about 2 billion, and that lowering desired family size in these countries would reduce the projected population by an additional billion.[22]

In the global projections discussed here, population policy efforts and effectiveness are implicitly accounted for because they are assumed to speed fertility decline, but population policies do not explicitly enter the projection process. Measuring the influence of family planning programs on fertility is difficult, although analysts have quantified program effort and effectiveness. Demographers Parker Mauldin and John Ross, for example, took program effort into consideration in their short-term projections for 37 less developed countries, but only in establishing uncertainty, not in the fertility projections themselves.[23] Measuring the effect of policies that enhance women's status or promote economic development on fertility decline is even more problematic.

Eventual Fertility

Demographic transition theory provides the basis for the expectation that today's high fertility countries will experience, or continue to experience, fertility declines. The theory provides little guidance, however, on the long-term average fertility level these countries might eventually reach. It also has little to offer demographers grappling with the question of future fertility trends in countries that have already completed the transition to low fertility.

Traditionally, many demographers assumed that fertility in all countries would eventually stabilize at replacement level, leading to stabilization of population growth. Long-term population projections reflected this thinking by setting replacement level—about two children per woman—as the level at which each country's TFR would stabilize. Technically, replacement level is reached when each couple has a daughter who survives to childbearing age to have her own children. Because some daughters will die before having children—and because slightly less than one-half of all births are females—the TFR must be just above 2.0 to maintain replacement level. A replacement-level TFR is slightly less than 2.1 children per woman in more developed countries where mortality rates are low, but is as high as 2.6 in Africa and 2.4 in South Asia where mortality is higher.[24]

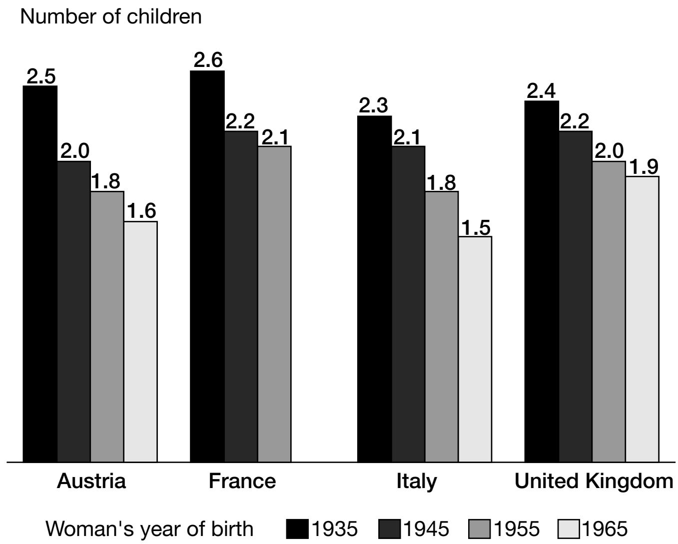
There are two general arguments in favor of the assumption that fertility will stabilize at replacement level in the long term. First, replacement-level fertility is a convenient mathematical benchmark for demographers preparing population projections—although it may not be the "most likely" outcome. Second, replacement-level fertility has been supported by a view that holds that demographic rates of a population are not just the sum of individual behavior, but also reflect the tendency of the demographic "system" to maintain itself.[25] The demographic system operates through the interplay of the vital rates and the population age structure and is assumed to seek homeostasis, under which birth rates would equal death rates, and the population would neither grow nor decline. This view interprets the falling mortality rates that mark the onset of the demographic transition as a perturbation of a system in balance; birth rates fall as the system inevitably re-establishes the balance between the two rates, and fertility seeks replacement level.

The idea that low TFRs will eventually rise to replacement level and stabilize has been strongly criticized as assigning a magnetic force to "replacement level" fertility, without any empirical evidence that TFRs will naturally drift to that level.[26] Total fertility has been below replacement level in 20 European countries for at least two decades, and it is currently below 1.5 children per woman in 21 European countries.[27] In eastern Germany, northern Italy, and the most urbanized regions of the Russian Federation, fertility has been at or below one child per woman.[28] Fertility has also fallen below replacement level in China, Thailand, and North and South Korea, and several other less developed countries. By 1995, 45 percent of the world lived in countries with below-replacement fertility.

There are many arguments that support the idea that fertility will decline below replacement level in more populations. These arguments

Traditionally, demographers have assumed that populations would eventually stabilize.

Figure 3
Completed Fertility for European Women, Selected Countries and Birth Cohorts



Note: Completed fertility for each birth cohort refers to the average number of children women had by age 45.

Source: Council of Europe, *Recent Demographic Developments in Europe 1999* (1999): 78.

can be grouped under the term "individuation," which encompasses the weakening of family ties, characterized by declining marriage rates and high divorce rates, the increasing independence and career orientation of women, and value shifts toward materialism and consumerism.[29] Individuation, together with increasing demands and personal expectations for the amount of attention, time, and money devoted to children, is likely to result in fewer couples that have more than one or two children and an increasing number of childless women. Demographer Antonio Golini has speculated that there might be an absolute lower limit of about 0.7 to 0.8 children per woman based on the assumption that between 20 percent and 30 percent of women remain childless and the rest have just one child. In principle, this would leave room for considerable further decline, but it remains unclear whether such a limit will be relevant for national fertility trends.[30]

While current trends and some plausible explanations may suggest that low fertility will continue, there is no compelling theory that can predict reproductive behavior in low-fertility societies. Although fertility typically continues to fall after reaching replacement level, there is no clear pattern to subsequent fertility trends. In some countries, fertility falls quickly to very low levels, while in others it has followed a more gradual slide. In the United States, Sweden, and some other countries, fertility declined well below replacement level and then rose nearly to replacement level again.

One argument against assuming that total fertility will remain very low in these countries is that the TFR is affected by changes in the timing of births even if the actual number of births women have over their lifetime does not change. Since the mean age of childbearing has been increasing in many industrialized countries over the past several decades, part of the decline in TFR has been due to this timing effect and not to a change in the completed fertility of women. Demographers John Bongaarts and Griffith Feeney argue that the TFR is likely to increase in the future once the mean age of childbearing stops rising, as happened in the 1980s in the United States when fertility rose to its current, near-replacement level.[31] An additional argument against continued very low fertility is that in surveys conducted in much of Europe, women consistently say they want about two children.[32] There are many reasons why women may fail to reach this target (career plans, divorce, or infertility, for example), but this finding suggests that fertility may be unlikely to remain extremely low, especially if societies make it easier for women to combine careers and childbearing.

Even if Europe's low fertility levels mask a pent-up demand for more children, however, the TFR in European countries may not rise to replacement level unless the younger women who are currently postponing births recuperate much of this delayed fertility at older ages.[33] This would mean a reversal of recent trends in cohort fertility—the total number of children produced by women from a given birth cohort. Cohort fertility was already below replacement level in most European countries for women born between 1945 and 1965 (see Figure 3).[34]

Feedbacks: Environmental Change and Fertility

It is well known that changes in fertility, through fertility's effects on population size, growth rate, and structure, can influence environmental conditions. Changes in the environment can, in turn, affect fertility. If such "feedback loops" are strong enough, it would be important to consider them when projecting future population growth. Historically, environmental change has affected fertility mainly though its impact on agriculture and food supply. In 16th- and 17th-century England, for example, a prolonged cool period was associated with a decline in grain yield, fertility, life expectancy, and population growth, while the average age at marriage and net out-migration increased.[35] Similarly, in China and Western Europe, periods of warmer temperatures between the 13th and 19th centuries have been linked to simultaneous increases in population growth rates.

Links between environmental change, agriculture, and fertility can be mediated by a number of factors. When facing an extended drought, for example, men in an agricultural community may leave their wives and community to seek work in adjoining agricultural regions or in cities.[36] Couples may delay marriage because they lack financial assets or housing. Fears of inadequate food supply may also induce changes in attitudes. The deterioration of natural resources in Ethiopia since the 1980s may have pushed women's preferences toward later marriage and smaller family sizes as well as encouraged greater use of family planning services.[37]

In each of these cases, however, environmental factors had relatively modest affects on fertility levels. Moreover, studies of historical periods are not always relevant to contemporary conditions when many economic, social, and technological factors have changed. For these reasons, long-term projections do not explicitly take into account environmental feedbacks on fertility.[38]

Future Fertility Levels

What do the historical records and current theories suggest about fertility trends in the future? Demographers at the major projection institutions have slightly different interpretations, which yield slightly different results. The differences are greater for specific countries and small regions than for the world as a whole.

All major global population projection series assume that the transition from higher to lower fertility will continue throughout the world. Projections vary in the pace of decline and in the ultimate fertility level.

The UN has historically assumed in its medium scenarios that fertility would level off at replacement level. In countries that had already dipped below that level, the UN invariably forecast TFRs to rise back up to about 2.1 children per woman. But as TFRs fell below replacement in more and more countries—including China, North and South Korea, and Thailand—and sank to previously unimaginable low levels in Germany, Italy, Spain, and other more developed countries, the UN and other groups changed their strategy. In their 1998 and 2000 revisions of *World Population Prospects*, the UN assumed that countries in which TFR is already below replacement level would remain below replacement level until 2050.[39]

For the long-term projections, however, the medium-scenario fertility in the low-fertility countries is assumed to rise to replacement level between 2050 and 2075, depending on the region. The UN appears to have assumed replacement level TFR in the long run to establish for Europe a benchmark scenario in which population ultimately stabilizes, not because it is judged to be the most likely scenario. The projection is described as representing "a conceptual dividing line between long-range future population increase and long-range population decline."[40] Projections prepared by the U.S. Census Bureau carry the assumption that eventual fertility will be below replacement level in a number of countries. IIASA adopted this assumption for all regions of the world in its central scenario.

When infant and child mortality decline, more babies survive to adulthood to have their own children.

In countries with fertility above 2.1 children per woman in 1990-1995, the UN maintains its historical assumption that fertility will undergo a smooth decline to replacement level and remain constant thereafter. The date that a country's fertility reaches replacement level is chosen based mainly on the current level of and recent trends in fertility and on comparisons with similar countries. The U.S. Census Bureau also assumes that fertility will eventually level off at about two births per woman, while IIASA assumes that, in the long run, fertility will decline below replacement level.

Projecting Mortality

Mortality projections are based on projecting life expectancy at birth—that is, the average number of years a child born in a given year can expect to live if current age-specific mortality levels continued in the future. Life expectancy (like the total fertility rate) measures the situation at a given period of time; it does not reflect the actual experience of an individual. Nonetheless, life expectancy provides a useful summary of the mortality rates for each age and sex group in a population at a particular time.

Projections of mortality must specify how the distribution of mortality over different age and sex groups may change over time. Changes in mortality at different ages have different consequences for population growth and age structure. When child and infant mortality decline, for example, a greater proportion of babies will survive to adulthood to have their own children and contribute to future growth. Mortality declines among the older population have a more short-term effect on population growth because the survivors are already past reproductive age.

Conceptual Basis for Projections

Uncertainties about future changes in life expectancy are quite different in high- and low-mortality countries. Low-mortality countries, primarily in the more developed regions, have seen their life expectancies increase to levels once considered a biological upper limit to the human life span. Future improvements depend mainly on whether or not such a limit exists and, if it does exist, how soon it might be reached. In less developed countries where mortality remains high, future life expectancy will be determined by the efficiency of local health services, the spread of traditional diseases such as malaria and tuberculosis, and new diseases such as HIV/AIDS, as well as living standards and educational levels. The gap in life expectancy between more developed countries and less developed countries has narrowed over the past 50 years, and is likely to narrow further unless the AIDS epidemic stalls progress in a significant number of less developed countries.

In more developed countries, mortality is concentrated at old ages, so uncertainty about future life expectancy is based on uncertainty about future death rates among the elderly. Death rates have been declining steadily for this age group, but there is a range of opinions on how long this trend can continue.

One point of view is that life expectancy in more developed countries is unlikely to increase well beyond 85 years from its current level of about 75 years. Some argue that this age represents an intrinsic (genetically determined) limit to the human life span.[41] Improvements in mortality that do occur are likely to increase an individual's chances of surviving to the maximum life span, but not to extend the maximum itself. Other researchers argue that while the intrinsic limit may be modifiable, in practical terms it is unlikely to be exceeded without medical breakthroughs.[42] This view is based on calculations showing that increasing life expectancy to 85 years would require dramatic reductions in mortality rates, particularly among the elderly. Following this line of reasoning, complete elimination of deaths from diseases such as heart disease, cancer, and diabetes—which account for a large proportion of deaths among the elderly—would not extend average life expectancy beyond 90 years. Only breakthroughs in controlling the fundamental rate of aging could achieve substantially longer life expectancies.

Other researchers hold that reduced mortality among the oldest ages could produce substantial improvements in life expectancy. Data from several more developed countries show that death rates at old ages have been falling over the past several decades, and this improvement has been accelerating, not decelerating as would be expected if a limit were being approached.[43] In attempting to understand this trend, researchers are investigating the evolutionary basis for aging.[44] Evolutionary biologists and biodemographers theorize that senescence—the degeneration of cellular processes over time—is an inadvertent consequence of sexual reproduction. Genes responsible for lethal diseases that usually affect people when they are past childbearing age tend to evade the influence of natural selection because, unlike genes associated with diseases earlier in life, these genes are passed on before they are expressed.[45] Thus mortality rates inevitably rise after the reproductive period. Intriguingly, increases in mortality decelerate at older ages, not only in humans but in several other species as well.[46] No single evolutionary theory satisfactorily explains this empirical finding.

The likelihood that biological or practical obstacles to overcoming this genetic legacy will be surmounted in the foreseeable future remains an open question. If they are, a significant increase in life expectancy could have a large impact on projected population. In a hypothetical case, if life expectancy were to increase to 150 years over the next two centuries, global population would stabilize at a level twice as high as it would if life expectancy did not exceed 85 years.[47]

In most less developed countries, possible limits to the life span are not as relevant to projections because life expectancies are lower and mortality is not as concentrated at the oldest ages. Life expectancy in less developed countries increased from about 40 in the 1950s to just over 60 in the late 1990s, a remarkable achievement driven mainly by reductions in mortality from communicable diseases. Regional progress was variable, with the slowest gains in sub-Saharan Africa, where average life expectancy is just over 50, and the fastest in China, where life expectancy reached 68 in the 1990s. Projecting mortality in less developed countries is difficult because of the relative scarcity and poor quality of data on current and past trends. In addition, the future course of the HIV/AIDS epidemic could substantially affect mortality in many countries, especially in sub-Saharan Africa where HIV prevalence rates are especially high.

Effects of HIV/AIDS

HIV/AIDS brings premature death to the most economically active and productive population groups, and is imposing an enormous economic and social toll on the African continent. In addition, HIV/AIDS has slowed, and in some cases reversed, the impressive gains in life expectancy in the less developed countries over the past several decades. Sub-Saharan Africa has been most affected. In Botswana, for example, life expectancy has dropped from about 63 years in the late 1980s to 44 years in the late 1990s. Zimbabwe has seen life expectancy fall from 57 to 43 years over the same period, according to the UN.

The effect of HIV/AIDS on population growth and age structure is significant in countries with the highest prevalence. The UN estimates in its 2000 projection series that for the 35 African countries in which it adjusts its projections to account for HIV/AIDS, population size will be on average 10 percent lower in 2015 than it would be without any deaths from AIDS. In the nine most affected countries, AIDS mortality lowers the projected 2015 population by nearly 18 percent. An independent study shows that population size may well decline in Botswana where the HIV prevalence rate is estimated at more than 30 percent of adults.[48] Moreover, the age structure will become severely distorted by AIDS deaths, which will have long-term effects on population growth. AIDS orphans, rising health expenditures, and a worsening health status of the labor force are likely to present major macroeconomic problems in addition to immense human suffering.

The ultimate impact of HIV/AIDS on the population of Africa as a whole will be moderate if exceptionally high HIV prevalence rates are limited to Botswana and a few other countries in South and East Africa. If prevalence rates increase in other sub-Saharan regions, HIV/AIDS will have a significant impact on population dynamics of the entire continent. HIV/AIDS could also affect population growth in Asia and Latin America and other world regions where the virus has spread.

Environmental Feedbacks and Health

Environmental change has had important direct and indirect effects on mortality in the past. Climate change, for example, probably contributed to the collapse of the Classic Maya culture in the Yucatan in A.D. 800-1000 and the decline of the Easter Island civilization in the 18th and 19th centuries.[49] When these massive disruptions occurred, however, the populations had extremely limited technical capacity to respond to change; the relevance of these ancient occurrences to future environmental change is unclear.

The most frequently discussed possibilities for future effects center on the idea of carrying capacity (the maximum number of people that the Earth can support) and the potential health impacts of climate change. Currently, however, population projections do not take explicit account of possible environmental feedbacks on mortality, based on the belief that they are unlikely to be an important determinant of future mortality trends.[50]

The concept of carrying capacity has its roots in ecology and the population biology of nonhuman species. Simple models of population growth that assume a limit to population size give rise to a logistic—or S-shaped—growth pattern, in which population size increases quickly at first, then more slowly as it approaches its ultimate limit. There is a long history of estimates of the Earth's human carrying capacity, based mainly on the idea that a growing population will eventually trigger an increase in death rates as it pushes up against the limit of the planet to provide the resources necessary to support life. Proposed limits have been based on a wide range of factors, including supplies of energy, food, water, and mineral resources, as well as disease and biological diversity. No consensus on the human carrying capacity has emerged; on the contrary, the range of estimates has widened over time.[51]

Carrying capacity is not considered in long-term population projections for at least three reasons. First, there is no agreement on what the limiting factors to population growth might be. Any proposed limit relevant to projections over the next century or two would depend primarily on which factor or factors were assumed

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Concern about increasing HIV/AIDS deaths has prompted proactive public health efforts—such as distributing HIV-prevention materials at this soccer stadium in Kenya. Future HIV-AIDS mortality is a major uncertainty in population projections, especially for sub-Saharan Africa.

to be limiting, as well as on how thinly any one factor had to be spread to begin to exert its limiting influence. While food is often taken as a limiting factor, for example, the maximum population that could be fed would depend on, among other things, the typical diet, agricultural productivity (which would depend on technology, agricultural research, irrigation, and other factors), the allowable fraction of land usable for agriculture, and so on. In addition, a factor that may be scarce in one region may be available in excess in another and, therefore, inter-regional trade might overcome limits in particular areas.

Second, even if the relevant factors could be agreed on, it may be too difficult to project the future evolution of those factors for use in population projections.[52] Future agricultural systems, energy supplies, and water availability are difficult to foresee in their own right, and there is no consensus in these areas to which demographers might turn. Third, even if these factors could be reliably predicted, their effects are mediated through economic, political, and cultural systems in ways that are not possible to quantify with confidence.

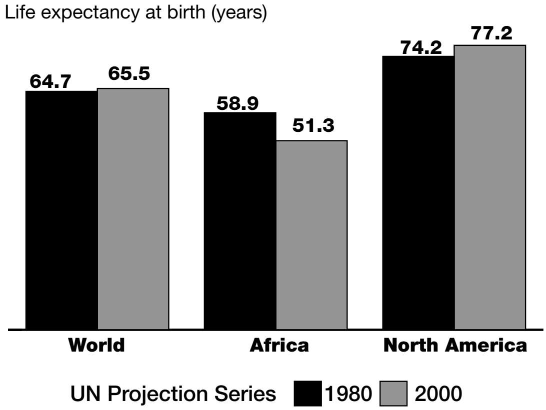
Although no long-term projections routinely take carrying capacity into account, some researchers have argued that it may be worth considering these limiting factors. Limiting factors might be especially relevant when projecting populations over long time horizons, in particular locations where resources are especially limiting and potential for trade is low, or when analyzing the relationship between demographic factors and specific environmental constraints.[53]

IIASA demographer Wolfgang Lutz and colleagues examined the potential demographic consequences of an assumed carrying capacity of 2.5 billion for sub-Saharan Africa to illustrate how such an exercise might be carried out. They demonstrated that if war, famine, disease, or some other catastrophe increased mortality by 20 percent but left fertility unchanged at a high level, the population of the region would regain its 20 percent loss within 10 to 15 years. The rate of demographic recovery depends on the age and sex structure of the mortality reduction as well as on assumptions regarding fertility, so that incorporating carrying capacities into population projections requires a fairly detailed accounting of the effects of a catastrophe on demographic variables.

In addition, some projections take environmental feedbacks into account indirectly. The IIASA methodology for developing probabilistic projections implicitly includes a small possibility of a substantial increase in future mortality, allowing for the possibility of negative feedbacks from environmental changes such as global warming.

Environmental effects on mortality short of a large-scale catastrophe have received increasing attention recently, especially those that might be driven by future climate change. Climate change could cause infectious diseases to spread to new populations.[54] An increase in such severe weather as

Figure 4
Projected Life Expectancy for 2000 in the 1980 and 2000 UN Projection Series, Selected Regions



Sources: United Nations, *World Population Prospects as Assessed in 1980* (1981); and United Nations, *World Population Prospects: The 2000 Revision* (forthcoming 2001). (Medium scenarios)

intense heat waves and storms that might accompany global warming may also have health consequences.

Warmer temperatures may extend the ranges and accelerate the life cycles of mosquitoes and other disease vectors and facilitate the spread of infectious and parasitic diseases. Annual fluctuations in climate have been tied to increases in malaria. For example, an increase of 1 degree Celsius in the average temperature in Rwanda in 1987 was associated with a 337 percent rise in the incidence of malaria that year. Other studies link malaria outbreaks over the past several decades in South Asia and South America with the El Niño-Southern Oscillation (ENSO) phenomenon, which periodically disrupts climate in particular regions around the world. Links between climate changes and other diseases have been identified as well. Biologist Rita Colwell attributes outbreaks of cholera in Latin America and Bangladesh in the early 1990s to El Niño events, although she noted that the epidemics behaved differently in Latin America according to prevailing levels of poverty, health education, sanitation, and other risk factors. Cholera outbreaks tended to be most widespread among low-income populations with limited access to public health and sanitation services. Other studies have shown that as temperatures have increased, one of the prime carriers of dengue and yellow fever—the *Aedes aegypt* mosquito—has extended its range to higher elevations in such diverse regions as Costa Rica, Colombia, India, and Kenya.[55]

If climate change leads to an increase in the frequency or intensity of extreme events, it will affect health conditions, particularly in less developed countries. Intense precipitation and flooding often spawns clusters of disease outbreaks, which might include cholera (a water-borne disease), malaria, and dengue fever. Severe drought often triggers migration, which can facilitate the spread of infectious diseases.[56]

The ultimate mortality impact of these environmental health risks is uncertain. Yet even the most pessimistic forecasts for additional deaths, when spread over large populations, do not significantly change the general outlook for mortality globally. Thus, while they may be of real concern, especially in selected areas, environmental health risks are not explicitly considered in producing medium- and long-range population projections.

Future Mortality

The UN has consistently revised upward its assumptions on the ultimate limits of life expectancy. In 1973, the UN life table models used to project mortality assumed that the highest life expectancies would be 77.5 years for women and 72.6 years for men. The most recent UN life tables assume an eventual maximum life expectancy of 87.5 years for males and 92.5 years for females. The UN estimates and projections of life expectancy in specific regions have generally increased as the theoretical maximum increased, but not for all regions. The 1980 UN series projected that Africa's average life expectancy would reach 58.9 years by 2000. This was too optimistic in part because of the HIV/AIDS epidemic: The most recent UN estimate shows Africa's average at 51.3 years in 2000 (see Figure 4).

The pace of change is determined by assigning to each country one of three models of change in life expectancy (fast, medium, and slow change), based on recent experience and on the idea that improvements in life expectancy will slow as life expectancy reaches higher levels. Countries may switch from one model to another, but no country actually reaches the maximum life expectancy by 2050.

The UN 2000 projection series incorporates the effects of HIV/AIDS mortality for 45 countries—primarily in sub-Saharan Africa—where at least 2 percent of the population was infected with HIV in 1999. It also explicitly accounts for HIV/AIDS mortality in Brazil and India, which had 1999 rates below 2 percent, but contained large numbers of infected persons. Models are used to estimate the annual incidence of the disease (the annual number of newly infected individuals), based on recent estimates of prevalence (the total number of HIV-positive individuals at a particular point in time). The models produce estimates of the annual number of AIDS deaths based on assumptions about the probability of progressing from HIV infection to AIDS and from AIDS to death. These additional deaths are then used to revise the projected mortality rates for a country.

The HIV/AIDS epidemic has lowered the projected life expectancy for less developed regions in recent UN projections. The most recent UN projection series shows life expectancy for less developed countries rising from about 62 years in 2000 to 75 years in 2045, more than one year less than the 76.4-year average life expectancy envisioned for less developed countries in the 1994 UN projection series.

In the past, IIASA has used three different scenarios for mortality change in its projections. The low-mortality scenario projects improvements in more developed countries of three years per decade, slightly higher than recent trends in Western Europe and North America, but lower than recent improvements in Japan. The high scenario projects increases of one year per decade in more developed countries. The central scenario, as an average of the high and low scenarios, assumes a two-year-per-decade increase in life expectancy.[57] In less developed regions, the high-, central-, and low-mortality scenarios assume life expectancy will increase at one, two, or three years per decade, respectively, with several exceptions. In sub-Saharan Africa, North Africa, and the Middle East, the range was extended to improvements of four years per decade in the low-mortality case to allow for the possibility that these regions will catch up with other regions of the world. Demographic assumptions for sub-Saharan Africa, South Asia, and Pacific Asia are also adjusted to take into account uncertainty associated with HIV/AIDS. In South Asia and China, life expectancy is projected to increase more rapidly for women on the assumption that the status (and therefore the health) of girls will improve in these societies. In its more recent probabilistic projection, IIASA used these and other considerations to define trends and uncertainty ranges for future mortality (see Box 3, page 12).

The Census Bureau projects future life expectancy in each country in a manner similar to the UN methodology. Maximum life expectancies of 82.6 years for men and 88.4 years for women are assumed based on the lowest cause-specific mortality rates currently observed anywhere in the world. These minimum cause-specific rates are combined into a single set of mortality rates from which the maximum life expectancies are calculated. The pace of change from current life expectancies is determined using a relationship that assumes that gains in life expectancy diminish as life expectancy itself increases.

Age-specific mortality rates in each year of the projection are derived by

The HIV/AIDS epidemic has lowered life expectancy for many less developed countries.

interpolating between current age-specific rates and the rates for a "model" set representative of low-mortality conditions.[58] In countries where the risk of death from HIV/AIDS is substantial, mortality is explicitly adjusted by modeling the spread of HIV infection and the development of AIDS. The at-risk countries identified in the most recent Census Bureau projection series include 21 countries in sub-Saharan Africa, plus Guyana, Burma, Haiti, Cambodia, Honduras, Brazil, and Thailand. The model projects the course of the epidemic through 2010 based on current and historical data. Rates of new HIV infection are assumed to peak in 2010, and AIDS mortality is assumed to decline to zero by 2060.

Migration

Future international migration is more difficult to project than fertility or mortality. Migration flows often reflect short-term changes in economic, social, or political factors, which are impossible to predict. And, since no single, compelling theory of migration exists, projections are generally based on past trends and current policies, which may not be relevant in the future. Even past migration flows provide minimal guidance because there is often little information about them.

Although fertility generally has a larger impact on long-term population growth, migration can exert a strong influence as well. In the early 1990s, for example, international migration accounted for nearly half of the population growth rate in more developed countries.[59] Migration effects are even more striking in particular regions and countries. In Western Europe, migration accounted for more than 80 percent of the average annual growth rate between 1990 and 1995. Migration also accounts for a substantial part of the population growth in the United States, Canada, and Australia. Growth rates in Italy, Germany, and the Russian Federation would have been negative without migration. Recently, the UN has projected levels of "replacement migration" in low-fertility countries out to 2050 that is, country-specific rates of in-migration required to maintain, in the face of continued low fertility, a given: total population, working-age population (15-64 years), and ratio of working-age to the old-age population the workers are expected to support. The migration streams required to maintain a stable population size were implausibly large compared with current net immigration flows and with the size of the receiving populations. This imbalance was especially notable for the amount of migration needed to needed to maintain the dependency ratio (the population ages 15–64 to the population age 65 or older and under age 15).[60]

While migration from less developed regions figured prominently in the population growth in more developed countries, migration had only a small negative impact on the 1990-1995 growth rate of less developed countries as a whole. Migration within less developed regions, however, played an important role in growth at the national level. Immigration—mainly the return of refugees from Malawi—accounted for one-third of Mozambique's nearly 4 percent annual growth in the first half of the 1990s. Similarly, while Guinea's population grew at nearly 6 percent per year, its growth rate would have been 4 percent without immigration, largely of refugees from Liberia.

Conceptual Basis

Projections of international migration generally begin with a consideration of current and historical trends.[61] Most projections foresee, for example, continued net migration into traditional receiving countries such as the United States, Canada, and Australia. These trends may then be modified based on potential changes in underlying forces affecting migration. These forces are complex, and no single factor can explain the history of observed migra-

Photo removed for copyright reasons.

This Brazilian family moved to northeastern Brazil in search of better opportunities—migration is a volatile demographic factor that responds to economic and political pressures and is often tempered by environmental conditions.

tion trends. Population growth rates in sending regions, for example, are not a good indicator of emigration flows. In general, correlations between rates of natural increase in less developed countries and levels of emigration to more developed countries have been weak or nonexistent.

A number of theories from different disciplines have attempted to explain migration flows.[62] In economics, international migration is viewed mainly as a mechanism for redistributing labor to where it is most productive.[63] Differences in wages among areas, combined with relative costs of migrating, are the main determinants of labor flows. Individuals decide whether to migrate by weighing the estimated benefits of higher wages in a new location against the costs of moving. The choice of destination will depend on where migrants perceive their skills to be most valuable.

This basic model, emphasizing the labor market, is generally regarded as an important component of explanations of migration, but it has been extended to address recognized shortcomings. So-called "new economics" models assume that migration decisions are not strictly individual but are affected by the preferences and constraints of families. Decisions are made not only to maximize income, for example, but also to meet family or household demands for insurance. By diversifying family labor, households can minimize risks to their well-being.[64]

Some researchers have argued that migration theory is incomplete without consideration of political factors, especially to explain why international flows are much lower than would be predicted based solely on economic costs and benefits.[65] Since a fundamental function of the state is to preserve the integrity of a society by controlling entry of foreigners, explanations must balance the interests of the individual with those of society as expressed through migration policies.

The various factors influencing migration decisions are often categorized according to whether they attract migrants to a region of destination ("pull" factors), drive migrants out of regions of origin ("push" factors), or facilitate the process of migration ("network" factors).[66] In addition to the factors evoked by the theories discussed above, others might include the need to flee life-threatening situations, environmental change, the existence of kin or other social networks in destination countries, the existence of an underground market in migration, as well as substantial income inequality and changes in cultural perceptions of migration in sending countries that are induced by migration itself.[67]

Environmental Feedbacks: Environmental Refugees

The role of 'environmental refugees' in population change is receiving increased attention.

The potential for growing numbers of "environmental refugees"—people driven to migrate by environmental factors—has received increasing attention since the term was introduced in the mid-1980s.[68] There is considerable disagreement on the relevance of environmental change to migration.[69] Some researchers characterize environmental conditions as just one of many "push" factors influencing migration decisions.[70] Environmental change, in this view, primarily acts indirectly by reducing income (by, for example, reducing agricultural productivity), making income less stable, or negatively affecting health or environmental amenities. Environmental change also acts in concert with other factors, which makes its relative role difficult to isolate.

Other researchers argue that deteriorating environmental conditions are a key cause of migration in less developed countries.[71] While factors such as poverty and population growth may interact with environmental change, environmental degradation is assumed to play a principal role.

This disagreement is reflected in the controversial nature of the definition of the term "environmental refugees" and of estimates of their numbers. Environmental scientist Norman Myers defines environmental refugees as "persons who can no longer gain a secure livelihood in their homelands because of drought, soil erosion, desertification, deforestation, and other environmental problems," and who "feel they have no alternative but to seek sanctuary elsewhere."[72]

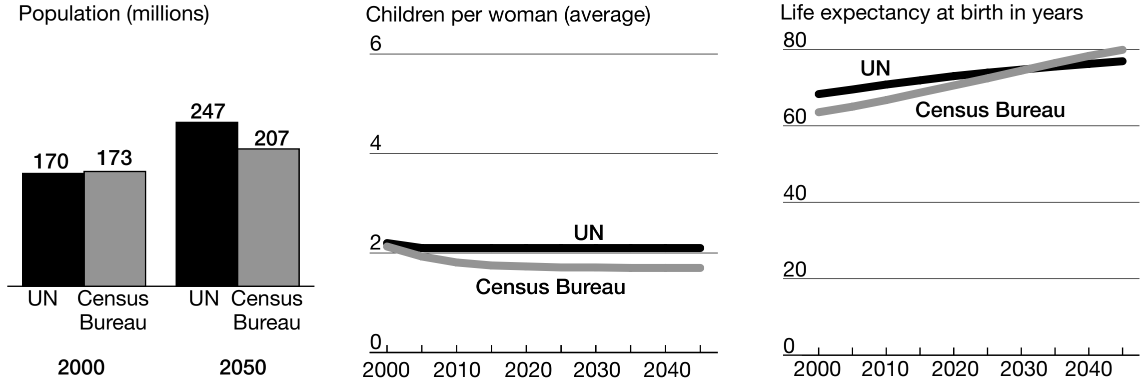
Others have argued that the term "refugee," with its associated image of human misery and chaos, overstates the case. The UN High Commissioner for Refugees defines a refugee as someone who has a "well-founded fear of being persecuted" in his or her country of origin "for reasons of race, religion, nationality, membership in a particular social group or political opinion." Many African and Latin American countries have extended the definition to include people who have fled from their homeland to escape generalized violence, internal conflict, and serious disturbances to public order.[73] Still, it is argued, "refugees" are commonly understood to be people who have left their region of origin involuntarily and in haste and are generally powerless and vulnerable in their new location. "Migrants," in contrast, move voluntarily and are in a much stronger position in their new residence than refugees. Acute environmental changes such as floods may cause sudden population movements that might be described as refugee flight, but people moving in response to chronic drought, progressive deforestation, and other types of environmental degradation are more appropriately defined as environmental migrants.[74]

The debate is more than academic. Some analysts equate the refusal to accept the "refugee" terminology with a refusal to recognize the issue as an important concern,[75] while others claim that the environmental refugee concept distracts attention from the pressing issues of refugees as traditionally defined.[76]

The degree to which environmental migration is relevant to long-term projections depends in part on the anticipated magnitude of the population movements. Myers estimates that environmental refugees (by his definition) currently number at least 25 million (with more than half of them in sub-Saharan Africa), a figure that is roughly equal to the number of refugees and displaced persons as traditionally defined.[77] Myers predicts that the number of environmental refugees is likely to double by 2010, and could swell to 200 million by 2025 because of climate change and other sources of environmental pressure.

The potential relevance of these figures to population projections also depends on the level of aggregation. Most environmental migration occurs within national boundaries and therefore would not affect regional or global projections. In addition, environmental migration may be less important to

Figure 5
Alternate Projections for Brazil: UN and U.S. Census Bureau



Sources: United Nations, *World Population Prospects: The 2000 Revision* (forthcoming 2001); U.S. Census Bureau, *World Population Profile 1998* (1999); and U.S. Census Bureau, International Data Base, accessed online at: www.census.gov/ipc/www/idbnew.html, on July 12, 2001.

projections than migration driven by other factors, such as economic imbalances among countries.

Because migration flows are so volatile, they are the most difficult demographic variable to forecast—yet migration will undoubtedly play an important part in the future size and characteristics of local, country, and regional populations.

While the major global projection series take migration into account in projections over the next half century, only IIASA incorporates migration into longer-term forecasts. Migration patterns in the less developed countries are based primarily on recent trends, as are the assumed destinations of migrants leaving sending regions. In the central IIASA scenario, the traditional receiving regions continue to absorb large migrant flows of roughly the same magnitude as recent trends (1 million annually migrate to North America, 500,000 to Western Europe, 175,000 to Pacific Asia).

Projection Outcomes

Given the difficulties of establishing baseline data and the inherent uncertainty in projecting trends in vital rates, different population projections can produce widely varying population sizes, age structures, and distributions. Projections series from various institutions do indeed span a wide range; however, there are some similarities between central or "most likely" projections and between plausible ranges of population size as projected by different institutions.

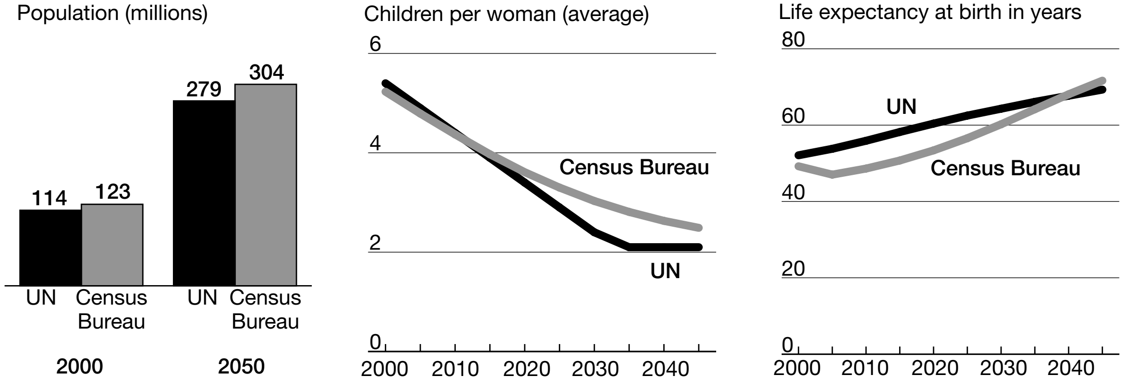
Population Size

The U.S. Census Bureau and World Bank projections, the central or "most likely" projection from the UN, and the median future population from IIASA's probabilistic projection are similar in some respects. The U.S. Census Bureau pegs world population at 9.1 billion in 2050, compared with 9.3 billion for the latest medium UN series and 8.7 billion for the World Bank, while IIASA's median value is 8.8 billion. The range of the various scenarios for the UN and IIASA is much wider: from 7.9 billion to 10.9 billion for the UN, and from 6.6 billion to 11.3 billion for IIASA's 95 percent confidence interval (see Appendix table, page 35).

Projections of global population growth tend to differ less across institutions than projections for smaller regions and countries because disagreements tend to cancel when regional projections are aggregated to

Figure 6

Alternate Projections for Nigeria: UN and U.S. Census Bureau



Sources: United Nations, *World Population Prospects: The 2000 Revision* (forthcoming 2001); U.S. Census Bureau, *World Population Profile 1998* (1999); and U.S. Census Bureau, International Data Base, accessed online at: www.census.gov/ipc/www/idbnew.html, on July 12, 2001.

global totals. The U.S. Census Bureau projects a significantly smaller 2050 population for Pakistan than does the UN, for example: 268 million vs. 344 million—even though the base population is similar. This difference reflects a lower future fertility and lower life expectancy. The Census Bureau also projects a significantly smaller population of Brazil for 2050 than the UN: 207 million compared with 247 million (see Figure 5, page 29). The populations for 2000 assumed by the Census Bureau and the UN are similar (about 173 million compared with 170 million), and life expectancy is higher in the Census Bureau than in the UN projection. The Census Bureau projects an average life expectancy of 78 years by 2050 compared with just under 69 years in the UN projection. The large difference in the two population projections for Brazil reflects the powerful effect that small differences in fertility rates can exert on future population size. The Census Bureau assumes that Brazil's TFR was 1.9 children per woman in 2000, just 0.3 below the UN estimate. Brazil's TFR levels off at 1.7 after 2020 in the Census Bureau projection, while the UN holds the TFR steady at 2.1 after 2010. The difference in fertility rates yields a difference of 40 million persons by 2050.

In some cases, agreement in projections of population size can mask large differences in underlying assumptions. In other countries, such as Nigeria, a scarcity of reliable demographic data means there can be widely differing estimates of current population size, fertility, and mortality—which can produce very different population projections. As demonstrated in Figure 6, the projections of Nigeria's population to 2050 begin from a very different estimate for 2000, and reflect alternate paths of fertility and mortality.

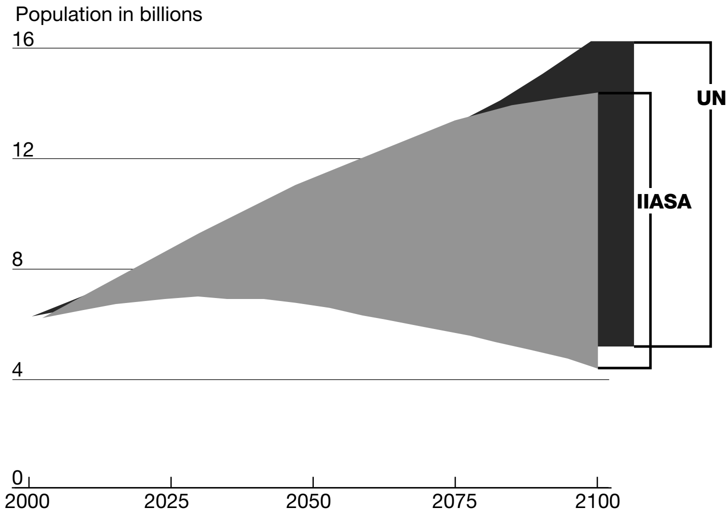
Differences between projected sizes of regions, which aggregate many countries together, tend to be smaller. UN and Census Bureau projections of population for the world, Europe, Asia, and Oceania differ by only a few percent between 2000 and 2025. Differences in Africa are larger, approaching 5 percent around 2025, and there is a growing difference in the projected population of Latin America (more than 5 percent by 2050).

UN projection series from 1994, 1996, and 1998 progressively lowered population projections, but the totals edged back up in the 2000 revision. Projected world population for 2050 dropped from about 10 billion in 1994 to less than 9 billion in 1998, a dramatic drop over a short period of time that received wide media attention. Nearly all of this change reflected lower estimates of current fertility and lower projected fertility in less developed countries. The 2050 projection of world population was back to 9.3 billion in the 2000 UN projection series, which reflected higher baseline population estimates for several countries, including Nigeria, as well as increases in current and projected fertility in several countries.

Long-Range Projections

Differences between the UN medium scenario and the median path of IIASA's probabilistic long-range projections increase over time. By 2100, projected world population differs by 11 percent: IIASA projects a median population of 8.4 billion that is already declining by 2100, while the UN projects a population of 9.5 billion that is nearly stable. The UN high and low scenarios span a wide range that is also generally higher than the IIASA range, as shown in Figure 7. The UN projects a global population of 5 billion to 16 billion by 2100, based on its low and high scenarios, while IIASA projects a 95 percent confidence interval of 4.3 to 14.4 billion. IIASA's projections are generally lower primarily because they assume that fertility will eventually fall below replacement level in all world regions. Figure 7 also shows that, based on the IIASA results, the UN high and low scenarios appear to be quite unlikely. One reason for this is that in the UN scenarios, fertility is high or low in all regions at the same time, while in the IIASA projections, high fertility in some regions are sometimes offset by low fertility in other regions, which tends to reduce the likely spread of future population sizes. Another reason for the narrower range of future population sizes in the IIASA scenarios is that fertility and mortality are correlated: Low fertility is offset somewhat by low mortality, and high fertility by high mortality.

Figure 7
UN and IIASA World Population Projections, High and Low Scenarios, 2000–2100



Note: IIASA= International Institute for Applied Systems Analysis.
The range for the UN projections (dark blue) are bounded by the high and low scenarios. The range for the IIASA projections (light blue) represent the 95-percent confidence interval—there is a 95-percent probability that future population size will fall within this range.

Sources: United Nations, *Long-Range World Population Projections: Based on the 1998 Revision* (1999); and W. Lutz, W. Sanderson, and S. Scherbov, *Nature* 412 (Aug. 2, 2001): 543-46. Data provided by IIASA.

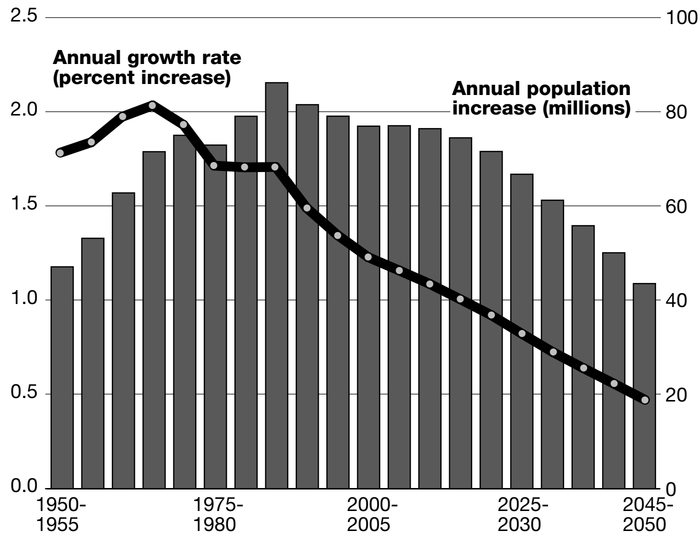
Population Momentum

Projections following different scenarios differ less in the short term than in the long term because they generally start from the same base population, and because it takes years for changes in vital rates to alter the built-in momentum that drives population growth. Momentum refers to the effects of population age structure on demographic trends: In a population with a young age structure, even if fertility falls sharply, the numbers of children will continue to increase for a generation as the cohorts of young people pass through their reproductive years. As a result, populations will continue to grow for decades even if fertility is instantly reduced to replacement level.

Some low-fertility industrialized countries are subject to negative population momentum. Their populations have aged enough to result in relatively small cohorts under age 30, and therefore even if fertility were to

Figure 8

Annual World Population Growth and Population Growth Rate, UN Projections, 1950–2050



Source: United Nations, *World Population Prospects: The 2000 Revision* (forthcoming 2001) (medium scenario).

rise to replacement level, population size would decline for some time.

The average age for the world population is still young, however, which favors continued growth even if fertility were to fall instantly to replacement level. In the UN instant replacement scenario, in which fertility falls to the level at which—over the long term—each cohort exactly replaces itself, world population grows from 5.7 billion in 1995 to 7.4 billion in 2025, and to nearly 9 billion by 2100.

The global population growth rate, which peaked in the late 1960s at above 2 percent per year, is expected to fall steadily from its current level of just under 1.4 percent annually to 0.5 percent annually by 2050 in the UN medium scenario (see Figure 8). The high and low scenarios show that the plausible range for these figures is -0.1 percent to +1.0 percent per year in 2050. While this represents a substantial range, in all cases the rate of growth is expected to decline and, in the low scenario, population stops growing altogether and begins to decline shortly before 2050.

The absolute growth in population peaked in the late 1980s at about 87 million per year. According to the medium scenario, growth will remain above 70 million per year until 2025 and will decline more steeply thereafter. The projected drop-off in absolute growth is not as great as the drop-off in percent growth because the population base is increasing over this period. The projected range of population increments is very large: In the high scenario, annual growth increases to 103 million around 2040 and begins a slow decline after 2045, while in the low scenario, annual additions to the population decline steadily after 2000 and turn negative after 2047. In 2050, an additional 102 million are added to the population annually under the UN high scenario, and nearly 8 million are subtracted from the total each year under the low scenario.

Implications of Future Growth

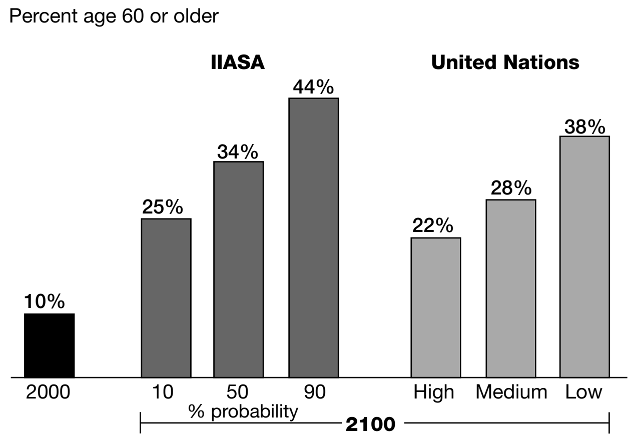
Under any of the scenarios for future growth, the world age structure will grow older, greater percentages of people will live in urban areas, and the regional balance will shift. These changes will be more dramatic further into the future. In 2000, the global population below age 15 was about three times the size of the population age 60 or older. The proportion age 60 or older is projected to swell in all scenarios while the proportion below age 15 shrinks. World population is youngest under the higher fertility rates in the UN high-growth scenario. In the UN medium scenario and the IIASA central scenarios, the proportion age 60 or older is likely to surpass the proportion below age 15 by the middle of the 21st century.

Based on the high and low scenarios from these institutions, however, the older age group could overtake the below-15 age group as early as 2030 or as late as the 22nd century.

This reflects the uncertainty in the rates of change in each of these age groups considered separately. While in all cases the proportion of the population below 15 is expected to fall, it could reach anywhere from 10 percent to 22 percent of the total population in 2100. Similarly, while the percentage age 60 or older will grow, the figure could be as low as 22 percent or as high as 44 percent of the population by the end of the century (see Figure 9). Other IIASA scenarios project a significantly wider range of uncertainty in future age structure because the correlation assumed between fertility and mortality in these scenarios reinforces differences in age structure at the same time that it narrows the range of future population size.

The proportion of the population ages 15 to 59 is projected to be somewhat more stable across scenarios and across time. This proportion is just under 60 percent in 2000 and falls to between 47 percent and 59 percent in all IIASA scenarios by 2100, and between 50 percent and 55 percent in the UN scenarios for the same year.

Figure 9
World Population Age 60 or Older in 2000 and 2100: Six Scenarios



Note: The IIASA percentages refer to the median and the 80 percent prediction intervals. There is a 10 percent chance the actual percentage age 60 or older in 2100 will be above 44, and a 10 percent chance that it will be below 25.

Sources: United Nations, *Long-Range World Population Projections: Based on the 1998 Revision* (1999); and W. Lutz, W. Sanderson, and S. Scherbov, *Nature* 412 (Aug. 2, 2001): 543-46.

Urbanization

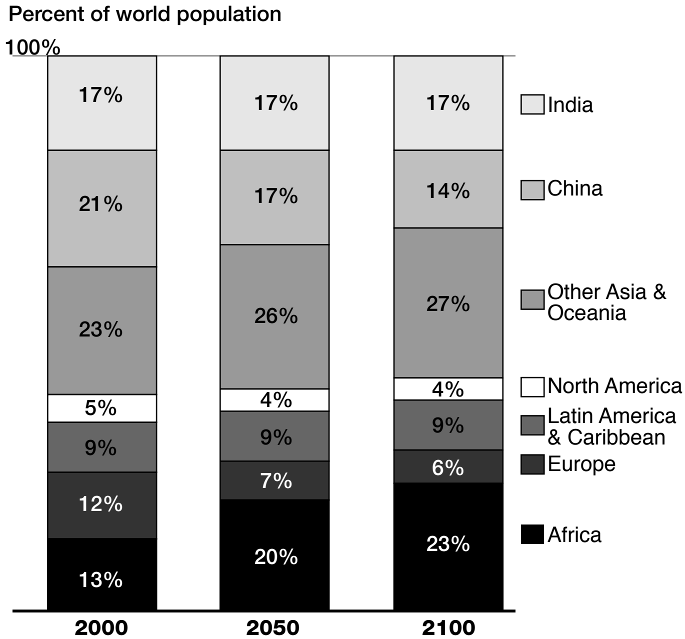
The UN is the only institution that produces projections of urban and rural population growth at the global scale. The UN projects the proportion of total population living in urban areas for each country, as well as the population of particular cities, for a single scenario to 2030. According to this scenario, the world is expected to continue a historical trend of increasing urbanization. In 2000, an estimated 47 percent of the global population resided in urban areas, and the urban population was growing three times faster than the population as a whole. Urban dwellers are expected to outnumber the rural population beginning in 2008, and by 2030, to make up 60 percent of world population. In more developed countries, the urban population is projected to rise from about 76 percent of total population in 2000 to 84 percent by 2030. In less developed countries, the urban proportion rises more steeply from 40 percent currently to 56 percent in 2030, which will narrow the gap in urbanization levels between more developed countries and less developed countries. There is a good likelihood that population will continue to shift from rural areas to urban centers in less developed countries well after 2030.

The projected rate of urbanization in the UN scenario implies that nearly all population growth over the next three decades will occur in urban areas. In fact, rural populations in several less developed country regions are expected to decline within a few decades.

Regional Balance

All of the global projections show that the regional balance of world population will shift over time. Under the UN long-range projections, the share of the global population made up by the current more developed countries of North America and Europe declines from about 17 percent in

Figure 10
World Population by Region or Country: UN Projections to 2050 and 2100



Source: United Nations, *Long-Range World Population Projections: Based on the 1998 Revision* (1999): Table 22.

2000 to about 10 percent in 2100 (see Figure 10). Africa's share of the total grows the most over this period, from 13 percent to 23 percent, while the contribution of China actually falls from 21 percent to 14 percent. These conclusions are qualitatively consistent across other scenarios, as well as across institutions.

Conclusion

The methods and assumptions for preparing world population projections are receiving more attention and closer scrutiny in the 21st century. Population projections are used in a widening array of fields, in part because of heightened concerns over the effects of global aging, the HIV/AIDS epidemic, and environmental degradation. While the basic methods for preparing population projections have changed little since the 1940s, demographers can draw on an expanding pool of data and on new developments in theories of demographic change. There is consensus on many aspects of future population trends: Global population will continue to grow, while the rate of growth is already declining steadily and is expected to continue to do so. Compared with today's world, the more populous world of the future will be older and live increasingly in cities; a growing share of the total will live in Africa and parts of Asia. Major uncertainties remain, however, including how fast and how far fertility will fall, whether low fertility levels will begin to rise, how much life expectancy may increase, and how migration patterns may change in the future. Demographers are developing new methods for characterizing the uncertainty that is inevitably attached to any population forecast, which will make projections more valuable for a wider range of users. Projecting future population will remain a challenging but increasingly important task in the coming decades.

Appendix Table

Projections of World Population to 2050 and 2100, Various Scenarios

Projection source	2050 Population in billions	Projection source	2100 Population in billions
Census Bureau	9.1	**UN Long-Range**	
		Scenario	
UN		High	16.2
Scenario		High-medium	13.4
High	10.9	Medium	9.5
High-medium	na	Low-Medium	6.3
Medium	9.3	Low	5.2
Low-Medium	na		
Low	7.9	**IIASA**	
		Median	8.4
World Bank	8.7	95% confidence interval	4.3-14.4
		60% confidence interval	6.4-10.7
IIASA			
Median	8.8		
95% confidence interval	6.6-11.3		
60% confidence interval	7.8-9.9		

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Suggested Resources

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International Institute for Applied Systems Analysis, Population Project
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U.S. Census Bureau International Programs Center
www.census.gov/ipc/www/

The World Bank
www.worldbank.org

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World Population Beyond Six Billion,

by Alene Gelbard, Carl Haub, and Mary M. Kent, 1999
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2001 World Population Data Sheet,

by Carl Haub and Diana Cornelius, 2001
(Available in English, French, and Spanish)
PRB's popular *World Population Data Sheet*, in a wallchart format and a 12-page book edition, contains the latest population estimates, projections, and other key indicators for 200 countries, including births, deaths, natural increase, infant mortality, total fertility, life expectancy, HIV/AIDS prevalence rates, urban population, contraceptive use, gross national income adjusted for purchasing power parity, land area, and population per square mile.
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Book Edition, (DB01WBK) $4.50

The World's Youth 2000,

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This 24-page report, and its accompanying data sheet, give a profile of today's youth, with a special focus on sexual and reproductive health. Topics include: population size and distribution, education, sexual and reproductive lives of young people, use of contraception, sexual violence against young women, HIV/AIDS, and policy and program approaches. (The report includes all the data in the data sheet.)
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