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A Guide to Global Population Projections

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Table of Contents

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Interdisciplinary studies that draw on long-term, global population projections often make limited use of projection results, due at least in part to the historically opaque nature of the projection process. We present a guide to such projections aimed at researchers and educators who would benefit from putting them to greater use. Drawing on new practices and new thinking on uncertainty, methodology, and the likely future courses of fertility and life expectancy, we discuss who makes projections and how, and the key assumptions upon which they are based. We also compare methodology and recent results from prominent institutions and provide a guide to other sources of demographic information, pointers to projection results, and an entry point to key literature in the field.

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1. Introduction

Demographic factors are important components of both the causes of and responses to future economic, environmental, and social change. Interdisciplinary studies of future global change can draw on projected trends in population size and growth rate, age structure, urbanization, and migration, among other variables. Often, however, integration does not proceed far beyond uncritical acceptance of a single projection of future population size. For example, studies of environmental change may use projections simply to scale per capita trends in other factors. Part of the difficulty in making fuller use of projections in such work stems from uncertainties in how demographics, acting in concert with social, economic, and cultural forces, may affect the environment. However, the historically opaque nature of the projection process has presented obstacles as well. How projections are made, the basis for key assumptions, and how projections differ among institutions that produce them has not always been clear to users, making the interpretation of results difficult.

We present a guide to long-term, global projections aimed at researchers and educators who might benefit from putting them to greater use. There has been a resurgence of research and new practices in projecting population that are likely to make results more useful and methodology more transparent. New thinking is being employed on how best to express uncertainty, on new methodological approaches to projections, and on the likely future courses of fertility and life expectancy. In addition, projections have demonstrated the importance of recent revisions to current estimates of demographic variables. In sections 2 and 3, we discuss the kinds and uses of projections, and the primary institutions producing long-term global projections. In section 4, we discuss projection methodology, reviewing the standard cohort-component method as well as alternatives, and discuss various approaches to expressing the uncertainty of projections. In section 5 we discuss the key assumptions upon which projections are based: baseline demographic data and trends in future fertility, mortality and migration. This section includes a discussion of the conceptual basis for projections of each component, possible environmental feedbacks, and a comparison of assumptions made by different institutions. Section 6 considers projection outcomes, discussing and comparing results of projected population size, age structure, and distribution. It also includes a discussion and analysis of the accuracy of historical projections.

2. Projections and their uses

Population projections (Note 1) differ widely in their geographic coverage, time horizon, types of output, and use. Spatial dimensions can range from local areas (like counties or cities) to the entire world. Local-area projections tend to use shorter time horizons, typically less than 10 years, whereas national and global projections can extend decades into the future, and in some cases more than a century. These longer-term projections typically produce a more limited number of output variables, primarily population broken down by age and sex. In contrast, projections for smaller regions often include other characteristics as well, which might include educational and labor force composition, urban residence, or household type.

The diversity of types of projections is driven by the diversity of users' needs (Lutz et al 1996a). Commercial organizations often use projections for marketing research and generally want a single most likely forecast. They typically want population classified by socioeconomic categories such 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 may therefore desire longer-term projections, and want to know more about the health status and living arrangements of the elderly.

The policy community, including advocacy groups, often would like alternatives to a single most likely scenario, including projections that reflect the influence of policy. For example, those concerned with the environmental impacts of population growth may be interested in the potential for reductions in such growth through population-related policies. In addition, they may want to know what the potential effect of environmental feedbacks on growth might be, a topic recently highlighted as underdeveloped by the National Research Council (NRC 2000). Global change researchers often use projections as exogenous inputs to studies on topics such as energy consumption, food supply, and global warming. These studies usually require projections with long time horizons (a century or more) and a range of scenarios rather than a single most likely projection.

We focus here on a relatively small subset of projections: long-term, global population projections – that is, sets of projections that may be made at the national or regional level but that cover the entire world. The time horizon of these projections typically ranges from 50 to 150 years. Demographers often feel uncomfortable making projections farther than a few decades into the future; uncertainty grows with the time horizon, and increases substantially beyond 30-40 years, 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 and educators. Only a few institutions produce such projections, but research and practice has been evolving rapidly.

3. Who produces projections?

The earliest systematic global population projection dates to Notestein (1945), although many national level projection efforts began over half a century earlier (see reviews by Dorn 1950 and Hajnal 1955). Since the 1950s, the United Nations (UN) has taken a leadership role in the production of projections and dissemination of their results. Later efforts, most of which continue to date, have been undertaken by three other institutions: the United States Census Bureau (USCB), the World Bank (WB), and the International Institute for Applied Systems Analysis (IIASA). Global long-run population projections tend not to be undertaken by individual researchers. Individual researchers have tended to create projections at the national-level (or below) and at this level have made significant contributions to varying methodologies (see section 4).

Table 1 reviews the basic features of the most recent projection made by the each of the four institutions. The time horizons vary from roughly 50 years to 150 years. The input assumptions upon which the projections are based — i.e., future rates of fertility, mortality and migration (see General Assumptions, below) — vary considerably, as does the number of output scenarios produced. Below we briefly summarize the historical experience of projecting population at each of these institutions.

Table 1: *Summary of projection characteristics, by key institutions*

Organization	Most Recent Projection	Time Horizon	Level of Aggregation	Fertility Scenarios	Mortality Scenarios	Migration Scenarios	Output Scenarios
United Nations, Revisions Series	1998*	2050	Country	4	1	1	4
United Nations, Long-term Series	1998	2150	8 regions	7	2	1	12
World Bank	1994-95	2150	Country	3	1	1	3
IIASA	1996[†]	2100	13 regions	3	3	3	27 + probabilistic projections
US Census Bureau	1998[§]	2050	Country	1	1	1	1
Population Reference Bureau	2000	2050	Country	1	1	1	1

* The UN has recently produced its 2000 Revision, but complete results were not available at the time of this writing.

† IIASA has recently updated its probabilistic projections, but full documentation is not yet available. Preliminary results are discussed in the main text.

§ In addition to these published projections, the USCB offers more recent projection output (2000) on-line (see: http://www.census.gov/ipc/www/idbsprd.html).

3.1 The United Nations (UN)

Between 1951 and 1998, the United Nations has produced 16 sets of estimates and projections covering all countries and areas of the world. Prior to 1978, new revisions were published approximately every 5 years; since then, they have been published every 2 years. These projections, published in their *World Population Prospects* series, include four scenarios which differ in their assumptions about future fertility rates: high, medium, and low fertility scenarios, as well as an illustrative scenario in which fertility is held constant at current rates.

The UN also produces long-range projections approximately every 10 years, which are based on and extend the most recent set of shorter-term projections. However the most recent long-term projections (UN 1999a) were produced just two years after the previous set. This unusually short interval was thought necessary due to substantial changes made in the 1998 Revision of World Population Prospects, which introduced new data and assumptions relative to the 1996 Revision, particularly new information on current fertility levels and the abandonment of the assumption that fertility in countries that are currently below replacement level (Note 2) would rise to replacement level before 2050. The long-term projections are produced for 8 major areas of the world and include seven scenarios which differ only in their assumptions about future fertility trends: high, medium-high, medium, medium-low, and low scenarios, as well as illustrative constant-fertility and instant replacement-level fertility scenarios. In addition, another five scenarios illustrate the influence of rising life expectancy on projection outcomes by pairing the first five fertility scenarios with alternative mortality scenarios in which mortality is assumed to remain constant after 2025 or 2050.

3.2 The World Bank

In 1978, the World Bank began producing population projections associated with their annual *World Development Report* (e.g., World Bank 1984). Projections are made at the country level, and until 1984 results were reported only for 1990, 2000, and the year in which the population became stationary (Note 3). More recent versions of the *World Development Reports* contain population projections out to 2000 and 2025, but not the year at which stationarity is achieved.

From 1984 through 1994-95 the World Bank produced a total of six roughly biennial long-term projections, out to 2150 (the first and last of these are Vu 1984; and Bos et al 1994). Until 1992-93, projections included only one variant. The 1992-93 and 1994-95 projections have a “base-case” and two alternative projections that assume either slow or rapid fertility decline (McNicoll 1992; World Bank, 1994). In additional to global population projections, the World Bank also produced numerous long-range regional projections. Since the 1994-95 projections, the World Bank no longer publishes their projection results although they continue to make long-term projections for internal use (e.g., for pension projects) (E. Bos, pers. communication).

Since 1997, the World Bank has included 40-year (45-year, starting in 2000) projection output as part of their *World Development Indicators* CD-ROM (cf., WB, 2000). Because the World Bank’s published projections are less than 50 years, we do not consider their projections in detail.

3.3 The United States Census Bureau (USCB)

The United States Census Bureau began producing global population projections in 1985, publishing them in the (nearly) biannual *World Population Profile* series (USCB 1985). Projections are made for all countries and areas of the world for a single scenario, and printed versions of their output show results for 15–25 years into the future. In the 1998 projections, results through 2025 are given, although output through 2050 is offered in an on-line service, which is generally updated annually (Johnson, pers. comm.). Additionally, they produce projections for the United States out to 2100 (USCB 2000).

3.4 The International Institute for Applied Systems Analysis (IIASA)

The Population Project at IIASA first produced a set of long-range global population projections in 1994 (Lutz 1994), and updated those projections in 1996 (Lutz 1996). Projections are made for 13 regions of the world through 2100, and three scenarios for fertility, mortality, and migration are considered. The full set of possible combinations of these assumptions leads to a total of 27 output scenarios, but even this understates the possible total because for a given migration scenario, different scenarios for fertility and mortality in each region can be selected and combined by the user without sacrificing self-consistency (i.e., net migration for the world is always zero). A unique feature of the IIASA projections is that they also provide probabilistic output: that is, the likelihood that population will reach a given size and age structure over the course of the projection period (see section 4). IIASA has recently updated their probabilistic projections, but details were not yet available at the time of this writing.

3.5 The Population Reference Bureau (PRB)

The PRB annually produces a *World Population Data Sheet*, which contains information such as population counts, fertility and infant mortality rates, doubling time, proportion urban and short population projections out to 2010 and 2025 for all countries in the world. Starting with their 2000 version of the Data Sheet, they have begun projecting population to 2025 and 2050 (PRB 2000). They distribute their output — total population size only, a single scenario — for all countries and select regions, via the web and hard copy.

Because PRB just began to include long-term projections, and because they limit their public output to total population size, we do not consider them in the remainder of this paper. However, since PRB's written materials do not indicate how their projections differ from others, we will do that briefly here. PRB uses a combination of country-supplied projections, projections produced by the UN or the US Census Bureau as well as generating their own in a minority of countries. Typically, they generate their own projections only when they have access to more recent or more reliable data on either baseline population, fertility or mortality, than either of the existing sources of projection output (D. Cornelius, pers. communication). Like the above institutions, they use the cohort-component methodology.

4. Projection methodology

4.1 The cohort-component method

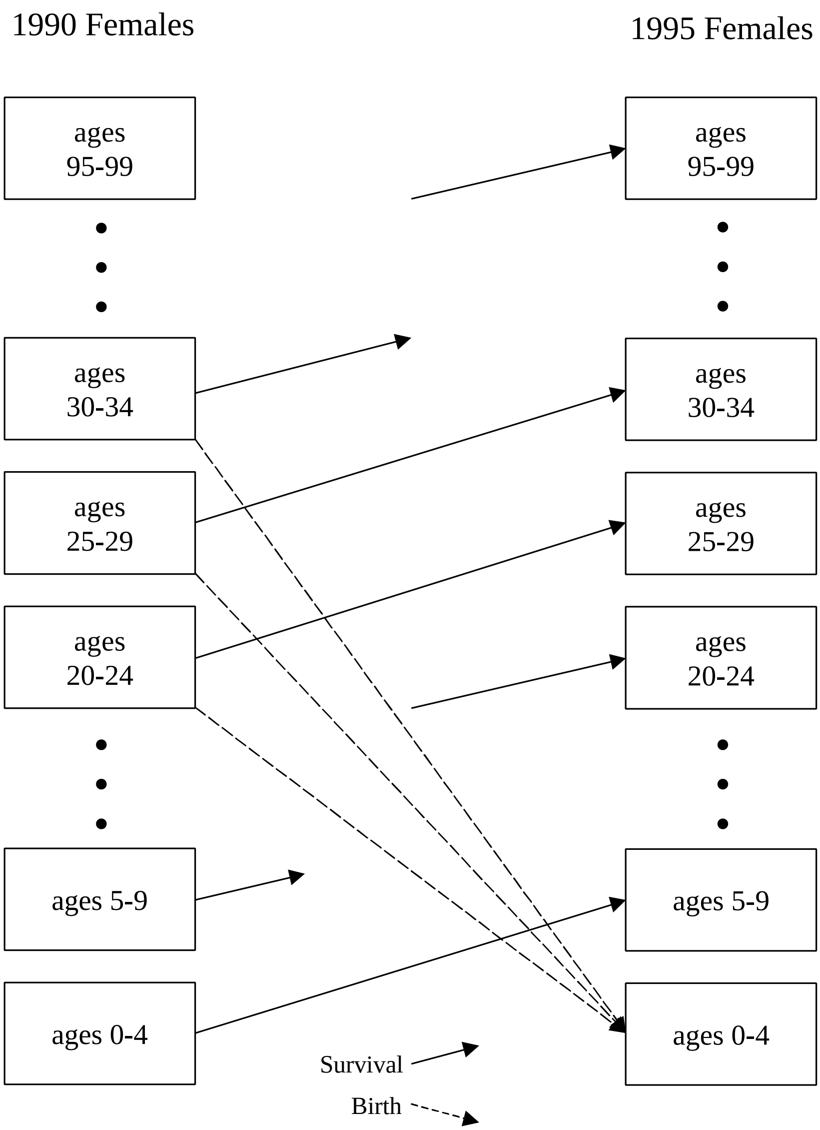
While some projections for individual countries or regions have been made with alternative techniques, all long-term global population projections employ the cohort-component method (Note 4). Initial populations for countries or regions are grouped into cohorts defined by age and sex, and the projection proceeds by updating the population of each age- and sex-specific group according to assumptions about three components of population change: fertility, mortality, and migration. Each cohort survives forward to the next age group according to assumed age-specific mortality rates. Five-year age groups (and five year time steps) are commonly used (although not strictly necessary) for long-range projections (Note 5). As an example, the number of females in a particular population aged 20-25 in 2005 is calculated as the number of females aged 15-20 in 2000 multiplied by the assumed probability of survival for females of that age over the time period 2000-2005. This calculation is made for each age group and for both sexes, and repeated for each time step as the projection proceeds. Migration can be accounted for by applying age- and sex-specific net migration rates to each cohort as well, and ensuring that immigration equals emigration when summed over all regions.

The size of the youngest age group is also affected by the number of births, which is calculated by applying assumed age-specific fertility rates to female cohorts in the reproductive age span (see Figure 1). An assumed sex ratio at birth is used to divide total births into males and females.

Development of this approach was the major innovation in the evolution of projection methodology. It was first proposed by the English economist Edwin Cannan (1895), and was then re-introduced by Whelpton (1936), formalized in mathematical terms by Leslie (1945), and first employed in producing a global population projection by Notestein (1945). Prior to the mid-20th century, the few global population projections that had been made were based on extrapolations of the population growth rate applied to estimates of the total population of the world (Frejka 1981, 1994).

Since Notestein's 1945 projection, the cohort-component method has become the dominant means of projecting population and has remained essentially unchanged, except for extensions to multi-state projections and innovations in characterizing uncertainty as described below. A fundamental feature of the method is that the projected size and age structure of the population at any point in the future depends

Figure 1: *An illustration of one time step of the cohort component method for a female population. (After Cohen 1995, Figure 7.2).*



entirely on the size and age structure at the beginning of the period and the age-specific fertility, mortality, and migration rates over the projection period. Uncertainty in projection outcomes arises not from uncertainty in the formal projection model itself, but from uncertainty in the baseline population data and the assumptions of future trends in vital rates.

The fact that projecting fertility, mortality and migration plays a central role in the cohort-component methodology is considered a strength because it allows demographers to draw on specialized knowledge of each of these components of population change. Institutions therefore normally project trends in vital rates based on expert opinion. Historically, however, it has been difficult to determine precisely how knowledge has been applied to such projections. Assumptions and reasoning have been hidden behind a "veil of secrecy" (Ahlburg and Lutz 1998). For example, while both the UN and the USCB provide general descriptions of their methodology (UN 1999a, 1999d, USCB 1998), neither institution provides a detailed accounting of the reasoning underlying the specific assumptions made for different countries and regions of the world. In general terms, the UN arrives at scenarios for future trends in vital rates through the use of in-house expertise, supplemented by consultation with groups of experts that are occasionally convened to discuss specific topics.

IIASA's projections have been somewhat more transparent in that they are based explicitly on the results of discussions of a group of experts on fertility, mortality, and migration that is convened for the purpose of producing scenarios for these vital rates. In addition, IIASA publishes sets of background papers written by expert group members that inform its projections and also documents its method of drawing on expert opinion (Lutz 1994, 1995, 1996). However, even in this case it is impossible to capture all of the factors considered in the decision-making process. For example, while the original goal for the IIASA expert group was to come to consensus on projected high and low values for vital rates that would cover 80-90% of possible future values in major world regions for a target year of 2030, group discussion was inconclusive (Lutz 1995). Therefore, three IIASA authors chose the high and low values for each region and vital rate after the meeting, based on their own knowledge and informed by the discussion at the meeting. Their choices were then sent to the participants for comment, which produced only minor subsequent modifications. The exercise convinced the authors that ultimate responsibility for defining assumptions could not practically be shared across a broad group of experts, although expert input was essential to the task. Research continues on effective means of employing expert opinion in projections (Ahlburg 2000), and IIASA plans to further develop this methodology for future projection efforts (Lutz et al 2000).

4.2 Alternative methods

4.2.1 Time series

Some national population projections have been made based on analyses of time series of either aggregate population size, or of vital rates. Aggregate time series models do away with the cohort component method entirely. For example, Pearl and Reed (1920), working before the cohort component method had been formalized and widely adopted, sought to apply a simple law of population growth such as the logistic (S-shaped) curve to extrapolate past changes in population size. Leach (1981) re-examined the approach using data from several countries and found it useful in describing historical changes in population size and for short-term projections. Marchetti et al. (1996) found that historical trends in total fertility and life expectancy, as well as population size, are well-approximated by logistic curves. However, in both of these more recent studies it was concluded that the logistic model provides little basis for extending trends into the long-term future. The fundamental difficulty is that a single logistic curve assumes a fixed limit to the variable being modeled, and in human populations those limits can be altered through changes in technology (e.g. changes in agricultural productivity, or health care) or social factors (e.g. changes in family size norms). Thus while a particular curve may fit historical observations, it does not provide any guidance on how the assumed limit may be altered in the future. Furthermore, a logistic function does not allow the direction of change to be reversed. For example, it does not allow for a decreasing population size, or a reversal in the direction of modeled fertility change.

Nonetheless, arguments have been advanced that simple extrapolation and more sophisticated aggregate time series methods still have much to offer projection methodology (Lee et al 1995, Pflaumer 1992). Such methods may in fact be more accurate than the cohort-component method over short time horizons (i.e., up to a few decades; Pflaumer, 1992; Rogers, 1995), and over longer horizons are useful in defining a minimum accuracy that more disaggregated methods should achieve to justify their use (for example, if a cohort-component projection can’t do any better than a simple extrapolation of growth rates, it may not be worth the additional effort it requires). One advantage of aggregate methods is that longer time series are available for total population as compared to the length of series for variables such as age specific fertility or mortality. Thus direct projections of population size may have more historical information upon which to draw than do cohort-component projections, which rely on projections of vital rates. Also, if basic causal factors such as ecological or economic limits to growth act more directly on total population, rather than on vital rates, it may make more sense to project total population directly.

However aggregate time series methods have several drawbacks. For example, confidence intervals quickly become large, limiting their usefulness for longterm projections. In addition, users often desire forecasts not only of total population size, but of age and sex composition as well. Therefore a disaggregated projection might be preferable even if it is no more accurate (Note 6). Perhaps more importantly, aggregate methods do not explicitly take into account the age distribution of a population, which affects the evolution of its size, and also may miss impending changes in the growth rate signaled in advance by changes in fertility or mortality (Lee et al 1995).

4.2.2 Microsimulation

In contrast to the cohort-component method, which treats each cohort as a homogenous group and uses average probabilities of birth, death, and migration, microsimulation treats each individual independently and uses repeated random experiments instead of average probabilities (van Imhoff and Post 1998). This technique simulates life events (marriage, divorce, the birth of children, leaving home, etc.) for each individual, and is usually based on a sample rather than an entire population in order to reduce computational demands; results are then scaled to the size of the total population. A drawback of the microsimulation method is that data requirements can be prohibitive, since probabilities for each life event must be estimated from event-history data. One main advantage of microsimulation is its ability to perform well even with large numbers of "states," or attributes of individuals. In a cohort-component model, the computational requirements for the projection quickly become unmanageable as the number of states increases, since the model must track every possible combination of states. In contrast, a microsimulation model tracks states for each individual in the sample, which is generally a much more manageable task. Since long-term global population projections incorporate only two states (age and sex), microsimulation is unnecessary. However, this method could play a role in studies of the environmental impacts of household consumption, which might require projections with much more detail in household characteristics.

4.2.3 Structural models

Long-term global population projections – and most projections over shorter terms or smaller regions – do not project vital rates based on formal models of how these rates may be related to socioeconomic factors. Trends in socioeconomic factors are thought to be harder to predict than the demographic processes themselves (Keyfitz 1982), and relations between demographic and other variables are not generally considered well known enough to quantify reliably (Cohen 1998). The best known example of an attempt to formulate a comprehensive, causal model of demographic processes is the World3 model that served as the basis for the Limits to Growth study in the early 1970s (Meadows et al 1971). The model projected future trends in population, economic growth, and natural resource use, and concluded that global society was likely to collapse in the future due to resource scarcity and environmental degradation. The model assumed fertility and mortality were complex functions of many factors, including population size, birth control effectiveness, health services, life expectancy, income, and industrial output per person. It was strongly criticized for having little empirical or theoretical basis to substantiate the forms used for these and other relationships in the model (e.g., Nordhaus 1973).

Recently, however, several researchers have argued that causal models of more limited scope can contribute usefully to population projections (Sanderson 1998, Ahlburg 1998). Some formal models of fertility, mortality, and migration that include socioeconomic variables (e.g., literacy and female labor-force participation rates) have been shown to produce more accurate forecasts than models that do not explicitly take them into account, and averages of results from the two methods performed better than either approach alone. Combining the results of forecasts produced using a range of different methods may be a source of innovation in future global population projections (especially those requiring greater detail about socioeconomic assumptions), although obstacles remain in selecting which results are of sufficient quality to include in such a procedure.

4.3 Multistate cohort-component projections

The basic cohort-component method of projecting population focuses on two characteristics of a population: age and sex. These characteristics are generally considered a minimum set not only because users are generally interested in them, but also because they are the most significant source of heterogeneity in the vital rates essential to projecting population. However, in some cases additional characteristics are of interest as well. For example, users might be interested in education levels, urban-rural residence, or the family type of individuals in a population. Even if these characteristics are not of interest to the user, they may be a significant source of demographic heterogeneity and therefore could potentially improve the accuracy of projections of population totals and age structure. Whether accuracy will actually be improved depends on whether causal factors for the additional characteristics are identifiable and well understood.

Projections that take additional characteristics, or "states," of a population into account are called multistate projections. Multistate projections using the cohort component framework were originally developed in order to account for the place of residence of population members (Rogers 1975) and have since been extended to other dimensions. For example, some multistate projections have taken education level into account since demographic rates are strongly correlated with education levels in many countries, and educational level is often of interest to projection users (Lutz et al 1998a). In some developing countries education level varies strongly with age (e.g., younger cohorts are more educated than their parents), and fertility varies strongly with education (in general, higher education is associated with lower fertility). Thus as time passes, women age into their reproductive years with higher levels of education than the previous members of the reproductive age group, and fertility may be lower than one would project without explicitly taking education into account. In addition, such projections show how the composition of the population by educational level might evolve. For example, building on previous work for specific regions of the world (Goujon 1997, Yousif et al 1996), Lutz and Goujon (submitted) produced the first global population projections by level of education, generating scenarios for 13 world regions to 2030. Results show that while at the global level educational composition changes only slowly and the gap between men and women is likely to persist, outcomes differ widely across regions. For example, due to large investments in education over the past several decades, China is likely to see the percentage of women over age 15 with some secondary education rise from 35 to at least 60. On the other hand, South Asia (mainly India) is unlikely to see the current proportion of 15% rise beyond 25% even under extremely optimistic assumptions.

A second example of multistate projections is the projection of households in addition to population. Van Imhoff and Keilman (1991) developed a multistate model that they applied to projecting households in the Netherlands; it has subsequently been applied to many other situations. More recently, Zeng et al (1998) developed a model that includes marital status (including cohabitation), parity (number of children ever born), number of children living at home, coresidence, and rural or urban residence. These models allows investigation of how changes in demographic factors such as marriage rates or the age at which children leave home can affect not only fertility and population growth, but also changes in the numbers, size distribution, and composition of households. This may be particularly relevant to energy and environment researchers, since household characteristics may be a key determinant of energy demand (O'Neill and Chen, submitted; MacKellar et al 1995).

Currently, none of the institutions considered here employ multistate methodology in generating long-term global population projections. Continued development may make the approach more popular in the future, in particular for consistent projections of urban versus rural population growth, which is not only an output of interest but also a significant source of heterogeneity in fertility and mortality. As emphasis on human capital and investment in education grows, more comprehensive projections incorporating education may be made as well.

4.4 Uncertainty

Accurately characterizing the uncertainty associated with a population projection is critical to ensuring that it is used appropriately. Many studies of global environmental change, for example, rely on a projection assumed to be the "most likely" outcome, and for this reason it seems widely agreed that it is important to provide users with such a projection. However, while it seems equally important to provide users with an indication of the uncertainty associated with the most likely projection, there is no generally accepted approach to characterizing this uncertainty, and in some cases (for example the projections of the U.S. Census Bureau) it is not done at all. The recent report of the U.S. National Research Council (NRC 2000) concluded that insufficient attention has been given to this issue by agencies making projections, and marks it as a priority for research. Different approaches to characterizing uncertainty can be grouped into two main classes: scenarios and probabilistic projections.

4.4.1 Scenarios

The most common approach is to present alternative scenarios that assume higher or lower vital rates than in the medium or central scenario. Terminology regarding alternative projections can be confusing. For example, the UN uses the term "variant" to describe alternative projections in its 1998 Revision, but uses "scenario" to describe alternative projections in its long-range projections. Lutz et al (1998b) note that the term "variant" is often used to define a population projection in which the underlying demographic rates are purely hypothetical and are not assumed to be dependent on external factors such as socioeconomic conditions. In contrast, the term "scenario," which IIASA uses to describe its projections, is defined as a consistent story in which fertility, mortality, and migration assumptions are embedded to provide a comprehensive picture of what the future might be. For simplicity, we call all sets of alternative projections scenarios, with the understanding that the story behind each scenario may be more or less well defined.

One strength of the alternative scenario approach is that in many cases users may need alternatives to a single central scenario, but still require self-consistent, independent scenarios rather than confidence intervals around a most likely projection. These alternative projections can be used in building up more comprehensive scenarios that may include many other components such as economic growth, technological development, and greenhouse gas emissions (Gaffin 1998).

However, the approach also has several weaknesses. The most important is that if no specific level of uncertainty is associated with the alternatives, it is not possible for users to interpret the precise meaning of the ranges presented. For example, the UN long-range projections include a high and low scenario in which fertility rates eventually become constant at about half a birth per woman higher or lower than in the medium scenario. Because these scenarios produce a global population that doubles or is halved every 77 years, the UN assumes that these projections are "unsustainable over the very long run" (UN 1999a, xiii), presumably because they would eventually lead to extinction or to implausible crowding. It therefore 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 1999a, xiii). However, despite the arguments ruling out population collapse or sustained rapid exponential growth, no other qualitative or quantitative probability is attached to any of the scenarios, nor is any set of socioeconomic conditions defined under which high or low population growth would be likely to occur.

Another problem with the scenario approach is that the choice of certain values for some assumptions may mean that choices for others are unreasonable. For example, the UN scenarios account for possible variations in fertility paths, but not for variations in future migration or mortality (except for a constant mortality case used to demonstrate the relative importance of mortality change to future population growth). On the one hand this approach simplifies interpretation of differences between projection results, which clearly demonstrate sensitivity to fertility assumptions alone. It also can be defended on the grounds that fertility has a larger influence on future population size and growth rates than either migration or mortality. On the other hand it has been criticized on the grounds that it misrepresents plausible future population paths because the conditions that are likely to be associated with lower fertility in developing regions are also likely to be associated with lower mortality (and, similarly, higher fertility is likely to be associated with higher mortality). The IIASA projections provide scenarios in which each vital rate is varied individually, but also provide scenarios in which fertility and mortality are varied jointly.

In addition, high or low scenarios assume that vital rates will be higher (or lower) in all regions simultaneously and over the entire forecast period. While this approach may provide a better bound on possible future population growth, it probably also tends to overstate the uncertainty in global population totals since it is likely that significant "canceling" would occur: some regions would follow paths higher than the central assumption while others followed lower paths, reducing the spread of future plausible paths. Both the UN and IIASA scenarios are subject to this weakness, although IIASA scenarios are provided at the regional level in such a way that users can choose to combine regional results from different scenarios and still maintain a self-consistent global population path (Note 7).

Finally, high and low scenarios intended to bracket the range of possible future population sizes will not necessarily also bracket the range of possible age structures or other demographic variables (Lee 1998). For example, although high population growth is generally associated with a young age structure, a path intended to produce the largest population will not produce the youngest one. Population grows fastest when fertility is high and life expectancy is long, but the youngest age structure is produced when fertility is high and life expectancy is short. Thus the scenario approach does not accurately reflect relative uncertainties in different demographic dimensions.

4.4.2 Probabilistic projections

An alternative to scenarios as a means of communicating uncertainty is to explicitly account for uncertainty in projected trends of fertility, mortality, and migration, and derive the resulting probability distributions for projected population size and age structure. 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.

4.4.2.1 Expert opinion

Among the institutions providing long-term global population projections, only IIASA provides probabilistic projections. The IIASA methodology is based on asking a group of interacting experts to give a likely range for future vital rates, where "likely" is defined to be a confidence interval of roughly 90% (Lutz 1996, Lutz et al 1998b). Combining subjective probability distributions from a number of experts guards against individual bias, and IIASA demographers argue that a strength of the method is that it may be possible to capture structural change and unexpected events that other approaches might miss. In addition, in areas where data on historical trends are sparse, there may be no better alternative to producing probabilistic projections.

However, there are a number of obstacles to this approach, including deciding who constitutes an expert and counteracting the observed conservatism in the projection of future trends. Lee (1998) questions whether experts can meaningfully distinguish between different confidence levels they may place on estimates of future vital rates. 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, there are no scenarios in which fertility starts out high, but ends up low, nor any scenarios with baby booms or busts. In addition, the possibility of capturing the potential for structural change may not be unique to the expert opinion approach; probabilistic projections based formally on errors from past projections implicitly contain information on past structural changes, such as world wars, the baby boom, the spread of modern contraception, the introduction of antibiotics, etc. (Lee 1998).

4.4.2.2 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 (1998) argues that, unlike methods based purely on expert opinion, these methods are capable of producing internally consistent probability distributions. While statistical methods also employ expert judgment, the mix of subjective and objective methodology is tilted more toward objective methods than is the expert-based method used in the IIASA projections. These methods have been applied only to some national projections (e.g., Lee and Tuljapurkar 1994, Alho 1998), but not to global projections, so they are not discussed further here. However they may be a source of further innovation in long-term global projections.

4.4.2.3 Historical error analysis

The analysis of errors in historical projections (see section 5.4) can be used as a basis for generating uncertainty intervals around a projection produced by some other means. For example, the NRC report (NRC 2000) produced a probability distribution for the UN medium scenario for population of individual countries, regions, and the world to 2050 based on analysis of errors in previous UN projections. This method rests on the assumption that current projections are subject to errors similar to those made in the past, although trends such as improvements in the quality of data on the initial population at the start of the projection can be controlled for. It is also limited by the short record (about 50 years) of past projections. Its strength is that it yields a probability distribution for a given projection that is consistent with the essential features of errors observed in the past. For example, errors grow with the length of projection at a pace based on past experience, and correlations in errors between countries or regions and over time can be accounted for. As an illustration, if large projection errors in some countries at a particular time have generally been associated with large errors in previous periods, or in neighboring countries, a statistical model based on historical experience can capture this tendency.

The results of the NRC uncertainty analysis showed that, averaged across 13 large countries, the 95-percent confidence intervals based on historical error analysis were more than twice as large as the range defined by the UN high and low scenarios, in both the short term and after 50 years. At a more aggregate level, this difference declined: averaged across 10 world regions, the 95-percent confidence intervals in a 50-year projection were about 40% larger than the UN high-low range. At the global level, the estimated 95 percent confidence interval was somewhat *narrower* than the UN high-low range. This pattern in the comparison of the two ranges occurs because the NRC analysis takes into account the cancellation of errors at higher levels of aggregation; that is, projected regional population sizes are less uncertain than projected sizes of the countries that make them up because over- and under-estimates for countries will cancel to some extent at the regional level. The same holds true in comparing uncertainty at the global and regional level. The UN methodology, based on the scenario approach, cannot take this phenomenon into account, and the high-low ranges are similar at all levels of aggregation. The NRC analysis also concludes that global population size is extremely unlikely to begin declining before 2050, even though it does so in the UN low scenario, and that the probability that the UN median scenario significantly underestimates future population size, while low, is higher than the probability that it is a significant overestimate.

4.4.3 Choosing a population projection

Users face a number of choices in selecting demographic inputs for their analyses. The considerations involved in such choices are many and varied, and depend on the nature of each application. While it is beyond the scope of this paper to discuss the larger question of how best to integrate demographic projections into integrated analyses, we offer some suggestions that follow directly from the discussion of different treatments of uncertainty in this section.

An overarching theme of the general discussion of scenarios and probabilistic projections is that uncertainty in demographic projections is large. It is therefore advisable to avoid using a single population projection for any analysis. Either a range of alternative scenarios, or a probabilistic projection, should be employed to reflect the inherent demographic uncertainty.

If it is decided that scenarios will be used, the choice of which population scenarios or set of scenarios to use should take into account the assumptions on which they were based and their sources of uncertainty. For example, to avoid internal inconsistencies, a population projection based on an assumption of slow economic development and incremental health improvements should not be used in a larger analysis that is based on a different set of underlying assumptions. This task is made somewhat difficult by the limited description of underlying assumptions for some population projections, but should be kept in mind. Users should also keep in mind that the range of uncertainty in particular demographic variables differs across a given set of scenarios. Recognizing that the choice of one set of high and low scenarios may bracket plausible population size ranges, but may not bound the set of plausible age distributions, would be essential for researchers investigating problems with both size- and age-sensitive characteristics. A relevant example is the analysis of future pension systems.

Probabilistic projections are attractive to particular applications, but can also inform analyses that are explicitly non-probabilistic. For example, some researchers exploring future scenarios of energy use and greenhouse gas emissions have taken probabilistic approaches and in the past have relied on deriving their own probability distributions for demographic parameters (e.g., Fankhauser 1994). This kind of work could benefit from the recent developments in probabilistic population projections. So, too, could analyses that explicitly avoid probabilistic interpretations. For example, the Intergovernmental Panel on Climate Change (IPCC) recently produced an updated set of scenarios for future greenhouse gas emissions (Nakicenovic et al 2000), with each scenario corresponding to one of four "storylines" regarding broad social, economic, and demographic development patterns. A wide range of input variables and resulting emissions paths are covered, but all scenarios are considered equally sound and interpretation of likelihood is left up to the user. In this case, users might draw on probability distributions of demographic projections to help judge how likely the particular demographic scenario used as a driving force in the IPCC scenarios might be, and therefore how likely the resulting emissions path itself might be.

One problem with probabilistic projections that must be kept in mind is that, whether they are based on expert opinion, statistical methods, or historical error analysis, they are generally unconditional; that is, consideration of future medical advances, socioeconomic development, and technological progress are all implicit in the probability distributions for vital rates and therefore for projection outcomes. However, many uses of population projections require conditional projections, including the "storyline" approach to developing scenarios of energy use and greenhouse gas emissions that pre-suppose particular socio-economic, technological, or political developments (see also Gallopin et al 1997). While it is possible to make probabilistic projections taking specific assumptions about determining factors into account, in practice users generally must rely on unconditional projections. With no way to adjust the distributions of output to account for different assumptions about underlying factors, users generally rely on alternative scenarios and must make their own judgment as to what scenario demographers had in mind when producing it and how well it matches their own assumptions. While it is unrealistic to expect agencies to produce conditional projections, better descriptions of the assumptions underlying scenarios or probability distributions might aid users in adapting them to their own needs.

Finally, in many cases it would be beneficial to include demographers on an interdisciplinary research team who can produce projections that are custom-designed for the question at hand. While this is not always feasible, where it is it would have the potential to greatly improve the self-consistency and rigor of the analysis.

5. General assumptions

The mechanics of projecting population growth from base year data and assumed future trends of fertility, mortality, and migration are straightforward and, except for methods of communicating uncertainty, essentially identical across institutions. The real challenge in projecting population lies in accurately determining the characteristics of the initial population (size, age structure, and vital rates) and in projecting future trends in vital rates, although it should be kept in mind that these two undertakings differ in a fundamental way: the characteristics of the initial population can be known with reasonable accuracy, given enough effort, while future trends in vital rates are unknowable. It is, in fact, for this reason that the methods for expressing uncertainty discussed in section 4.4 were developed. All projections of fertility, mortality and migration used in producing global population projections are based in some manner on expert opinion informed by current conditions, past trends, and theories about the determinants of changes in vital rates.

5.1 Baseline data

Accurate baseline data on population size and age structure, as well as on fertility, mortality, and net migration rates, are critical to producing accurate population projections (Keilman 1990). So, too, are accurate data on past trends in population dynamics and vital rates, which play an important role in informing forecasts of future trends. The primary sources of demographic data are national population censuses performed periodically in most countries of the world. In countries where census data is nonexistent or considered inaccurate, data from sample surveys are often used.

The United Nations Population Division produces the most widely used compilation of current and past estimates of population size, age structure, and vital rates based on these primary sources, and obtaining data and evaluating its quality and consistency makes up the bulk of the Division's efforts on demographic matters (Zlotnik, pers. comm.). It must be ensured, for example, that past trends of vital rates are consistent with past estimates of population size and age structure. In developed countries, detailed data on fertility and mortality is usually available, along with reliable periodic census counts. These can be combined to produce a relatively consistent picture of historical population change in these areas. However, even here data on international migration is often inadequate, and complete consistency between vital rates and population change is often achieved by assigning to net migration the residual estimate (Zlotnik 1999a).

Estimations for less developed countries are more difficult due to scarce and sometimes unreliable data. Often indirect estimation techniques must be used, occasionally by inferring rates and levels from other countries in the same region with similar socio-economic characteristics. However, over the past 20 years data collection efforts have increased substantially, and for the UN 1998 revision, 83 percent of all countries or areas had post-1985 census data available on population size and age structure (Zlotnik 1999a). Data on vital rates are often derived from surveys and are more problematic. Information on fertility and child mortality is generally more available than information on adult mortality. For example, countries accounting for about 5 percent of global population lacked data more recent than 1990 on fertility and child mortality. In contrast, countries accounting for 40% of global population lacked data from the 1990s on adult mortality (Zlotnik 1999a). This not only makes the estimation and projection of mortality trends difficult, but, coupled with unreliable census data, makes estimation of the baseline age and sex structure of the population difficult as well.

The US Census Bureau produces its own baseline data, although its estimates cannot be considered completely independent from those of the UN. Both organizations rely on the same data sources and use similar techniques for estimating demographic variables. There are differences between the institutions in when data becomes available to them and how raw data is analyzed and converted into estimates of demographic parameters (USCB 1998). However, in practice these differences have been very small at the global level. For example, estimates of 1990 world population differ by only 0.08 percent. For individual countries, differences can be larger: in 11 countries differences in population size are 10 percent or more.

IIASA used baseline data on population size, total fertility rates, and life expectancies from the Population Reference Bureau's 1995 World Population Data Sheet (see PRB 2000 for the most recent version), combined with age distributions of population and vital rates from the UN 1994 Revision (Lutz et al 1996b). The Population Reference Bureau bases its estimates on the work of the UN, and independent consideration of other sources including official country statistics, the Council of Europe, and the U.S. Census Bureau.

5.2 Projecting future fertility

In the long run, the level of fertility has the greatest effect on population growth because of its multiplier effect: additional children born today will have additional children in the future. Fertility projections are made by projecting the course of the total fertility rate (TFR) over time, and translating this total fertility rate into age-specific fertility rates. In general, the projection of TFR is divided into assumptions regarding a level at which fertility eventually becomes constant in the country or region, and the path taken from current to eventual levels. Once fertility reaches its eventual level, assuming mortality and migration rates are also fixed, the population will eventually reach a stable age structure and constant growth rate. If the eventual fertility level is at replacement level and net migration is zero, the growth rate will eventually be zero – that is, the population will not only be stable, but stationary as well. 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 (O'Neill et al 1999).

5.2.1 Conceptual basis for projections

For countries currently above replacement level fertility, demographic transition theory serves as the theoretical basis for forecasts. In addition, evidence from surveys indicates that desired fertility is significantly less than actual fertility in most less developed countries (LDCs) where fertility remains high, leading to the expectation of further declines.

5.2.1.1 Demographic transition theory

The concept of demographic transition is a generalization of the sequence of events observed over the past two centuries in the more developed countries (MDCs). While different societies experienced the transition in different ways, in broad outline these societies have gradually shifted from small, slowly growing populations with high mortality and high fertility to large, slowly growing populations with low mortality and low fertility (Knodel and van de Walle 1979). During the transition itself, population growth accelerates because the decline in death rates precedes the decline in birth rates.

Empirical evidence from all parts of the world overwhelmingly confirms the relevance of the concept of demographic transition to LDCs. The transition is well advanced in all regions except sub-Saharan Africa, and even here the beginnings of a fertility decline are becoming apparent. In several countries such as China, Taiwan, and Korea, fertility is already at sub-replacement levels. In many other countries in Southeast Asia and Latin America, fertility has fallen to levels seen just a few decades ago in MDCs.

The biggest difference between the transition in MDCs and LDCs has been the speed of the mortality decline. In Europe, North America, and Japan, mortality fell slowly for two centuries as food supply stabilized, housing and sanitation improved, and progress in medicine was made. In contrast, mortality in LDCs 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. One result is that LDC populations are growing much faster than did the populations of MDCs at a comparable stage of their own transition.

The earliest attempts to explain the demographic transition cited industrialization and urbanization as the ultimate driving force (Thompson 1930, Davis 1945, Notestein 1945). 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 was given theoretical rigor in the 1960s with the development of a theory based on changes in determinants of parents’ demand for children (Becker 1960, Becker and Lewis 1973, Becker and Barro 1988), which provided a micro-economic model describing choices parents are assumed to make between numbers of children and consumption of material goods at the household level. The model assumes that fertility falls because as societies develop, 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. In addition, some of the economic benefits parents may derive from children, such as household labor, income, and old age security, decline as a result of the development process. 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. Easterlin (1969, 1975) added supply factors (environmental and cultural effects on fertility in the absence of regulation) and costs (including the psychic, social, and monetary costs of fertility regulation) to the focus on demand.

Other explanations have given much more weight to sociological over economic factors. For example, Ryder (1983) argued 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. Caldwell (1982) 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, services, and guarantees against risk) from children to parents typical in pre-transition societies to a flow benefiting children. 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.

Other researchers have emphasized the role of cultural over socio-economic factors. Based on analyses of the fertility transition in Western Europe, Lesthaeghe (1983) argued that differences in fertility across societies were largely due to differences in religious beliefs and the degree of secularism, materialism and individuation. Cleland and Wilson (1987) 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. Bongaarts and Watkins (1996) demonstrated that diffusion of ideas and information about limiting fertility is important. 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 they have achieved the same level of development.

Demographic transition theory has been and continues to be a central focus of demography (van de Kaa 1996). While there are many ideas, each offering important insights, no single, simple theory explains the multi-faceted historical experience with transitions. Each explanation suffers from its own shortcomings, and for each exceptions can be found (Robinson 1997, Oppenheim Mason 1997). It is likely more accurate to think of transitions as being driven by combinations of factors rather than single causes, but determining the precise mix of factors likely to be at work in particular circumstances remains an elusive goal (NRC 2000, Oppenheim Mason 1997, Kirk 1996, Hirschman 1994).

Although the fact that demographic transition has occurred under so many different conditions and has likely been driven by multiple causes complicates study of the subject, in one sense it can be considered a strength where projections are concerned. It implies that transition is probably inevitable, so that the task of projecting future fertility in high fertility countries is to anticipate not so much whether countries will experience this phenomena, but when, how fast, and to what eventual end state.

5.2.1.2 Policies

The role of population policies in the decline of fertility in developing countries over the past several decades and by extension their potential role in future fertility trends is a matter of some debate. Implementation of family planning programs has been the main policy tool in the past (Note 8), and there are two main points of view on their effectiveness.

Proponents argue that programs have had a substantial effect on fertility primarily by reducing "unwanted fertility" (births that occur after a woman has reached her desired family size) below what it otherwise would have been (Potts 2000). The conventional justification for facilitating this reduction is based on survey data indicating that many women report wanting to avoid pregnancy but do not use contraception. Family planning programs therefore help meet this "unmet need" for contraception by assisting users in overcoming obstacles to contraceptive use, which can include limited access to services, lack of knowledge, fear of side effects, disapproval of families and others, and high cost (Bongaarts and Bruce 1995).

In contrast, Pritchett (1994a, 1994b) has argued that unmet need is much smaller than commonly assumed, and that fertility decline is driven primarily by declining desired fertility (that is, a reduction in the number of children women actually want) rather than a reduction in unwanted fertility. This conclusion is based on the high correlation between total and desired fertility, and the lack of correlation between total and unwanted fertility. He argues that because low fertility countries have low desired fertility, but not 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 an insignificant historical effect on fertility.

Bongaarts (1997) concludes that neither view is fully accurate; rather, both overstate their case to some extent. While there is substantial unmet need for contraception, the portion of it that is relevant to the potential for fertility decline is probably less than commonly cited by advocates of family planning programs, since these estimates include need for contraception for spacing children and meeting that need is unlikely to have a substantial effect on fertility. He also concludes that the effect of programs on unwanted fertility is likely substantial; the critics' view is based on a misinterpretation of the lack of correlation between total and unwanted fertility, which clearly exists but is not inconsistent with effective family planning programs. And finally, he argues that historically programs have in fact had a substantial effect on fertility: an estimated 43 percent of the fertility decline between the early 1960s and late 1980s was due to program interventions.

Future change in fertility will also depend on the extent and effectiveness of future policy. 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 the motivation for 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 them 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" between girls and boys. Although these goals are not primarily motivated by their potential effect on demographic trends, achieving them would likely lead to lower fertility. Bongaarts (1994) estimated that eliminating unwanted fertility in developing countries would reduce population in 2100 by about 2 billion, and lowering high desired family size, which could be achieved in part through the measures advocated in the Program of Action, would reduce population by an additional billion.

In the global projections discussed here, population policy efforts and effectiveness are implicitly accounted for, but do not explicitly enter the projection process. Although program effort and effectiveness can be quantified (Ross and Mauldin 1996), quantifying their influence on fertility remains difficult. For example, Mauldin and Ross (1994) took program effort into consideration in their short-term projections for 37 LDCs, but only in establishing uncertainty, not in the fertility projections themselves.

5.2.1.3 Eventual fertility

Demographic transition theory provides the theoretical basis for the expectation that currently high fertility countries will experience, or continue to experience, falling fertility rates in the future. It provides little guidance, however, on the long-term average level they 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, long-term projections have assumed that fertility in all countries would eventually stabilize at replacement level, leading to a stationary population. There are two general arguments in favor of this assumption. First, replacement level fertility may be seen not as the most likely outcome, but as a mathematically convenient benchmark which prevents population from steadily growing or declining (UN 1999a). Second, it has been supported on the basis of a systems view which 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 (Vishnevsky 1991). This view sees the falling mortality rates that mark the onset of the demographic transition as a perturbation of a system in homeostasis; birth rates fall as the system inevitably re-establishes balance between the two rates, and fertility seeks replacement level in order to preserve the system. Some researchers have speculated that fertility could be stimulated to rise to replacement level in currently low-fertility countries by a wide range of factors, including pronatalist government policies, increased nationalism, a renewed emphasis on traditional roles for women, or a shift away from materialist values (Day 1995).

However, the return to replacement fertility has been strongly criticized as an assumed magnetic force without empirical support (Demeny 1997, Westoff 1991, Lee 1991). 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 (UN 1999c). In large parts of several European countries (e.g. Eastern Germany, Northern Italy, and the most urbanized regions of the Russian Federation), fertility has been at or below 1.0 (UN 1997b). Several LDCs have reached subreplacement level fertility as well (e.g., China, Thailand, and North and South Korea).

In addition, there are many arguments supporting an assumption of fertility declines below replacement level. These can be grouped together under the term "individuation" (Bumpass 1990), of which there appears to be no end in sight: the weakening of family ties both in terms of declining marriage rates and high divorce rates, the increasing independence and career orientation of women, and the value change towards materialism and consumerism. Individuation, together with increasing demands and personal expectations for attention, time and also money to be given to children, is likely to result in fewer couples that have more than one or two children and an increasing number of childless women. Golini (1998) recently speculated that there might be an absolute lower limit of about 0.7 to 0.8 children per woman based on the assumption that 20-30% of women remain childless and the rest have just one child;

this would leave room in principle for considerable further decline, but it remains unclear whether this limit will be relevant to future fertility trends.

Unfortunately, while current trends and some plausible explanations may suggest continued low future fertility, there is no compelling and quantifiable theory of 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, in others it has made a more gradual decline, in some such as the U.S. and Sweden it has declined well below replacement level and then risen nearly to replacement level again (although Sweden has recently seen another rapid decline) (UN 1997b).

One argument against assuming that total fertility will remain very low in these countries is that because TFR is a period measure, it is affected by changes in the timing of births even if the actual number of births women experience 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. Bongaarts and Feeney (1998) therefore argue that 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 value just below replacement level. An additional argument against continued very low fertility is that in surveys conducted in much of Europe women consistently say they want about 2 children (Bongaarts 1999). There are many reasons why women may fail to reach this target (e.g. competing career plans, divorce, infertility), but this finding suggests that fertility is unlikely to remain extremely low, especially if societies made it easier for women to combine careers and childbearing.

However, it may be unlikely that TFR in European countries will return to near replacement level, even after postponement of childbearing has ceased. This will depend in part on the extent to which younger women who are currently postponing births will recuperate some of this delayed fertility at older ages, which will influence their cohort fertility (Lesthaeghe and Willems 1999). Cohort fertility was already below replacement level in most European countries for women born between 1945 and 1960 (the most recent cohorts for which reliable estimates of completed fertility can be made) (UN 1997a).

All institutions select an eventual fertility rate for their projections. Based on recent trends and current thinking about low fertility (NRC 2000), both the UN and IIASA have dropped the traditional assumption of convergence to replacement level fertility – for all countries in the IIASA projections, and for MDCs in the UN projections. Additionally, when projecting eventual fertility levels for the MDCs the UN now takes into consideration a measure of cohort fertility for the most recent cohort

(1962) for which it can safely be estimated. The USCB also assumes that eventual fertility will be below replacement level in many countries. It projects that currently high fertility countries will experience a decline to, or slightly below, replacement level. Other countries generally converge to levels between 1.7 and 2.0.

5.2.2 Feedbacks: Environmental change and fertility

Environmental change has had a historically important effect on various demographic rates, including fertility. For example, Galloway (1986) found that warmer than average periods in middle latitudes were associated with above average population levels, and vice-versa. The suggested mechanism was climatic influence on agricultural output and food supply per capita. Data from 16^{th} and 17^{th} century England show that during cool periods, grain yield, fertility, life expectancy, and population growth declined, while the average age at marriage and net out migration increased. Similarly, analysis of data from China and western Europe between the 13^{th} and 19^{th} century indicates that warmer temperatures have been linked to increases in population growth rates.

Links between environmental change, agriculture, and fertility can be mediated by a number of factors. Men may leave the community to seek work in adjoining agricultural regions or in cities (Lee 1990, Hill 1989). Marriages may be delayed because couples lack financial assets. Expectations and the incremental nature of many crises also play a role; for example, Dyson (1991) found an anticipatory demographic response in South Asia, where famines were preceded by extended periods of worsening adversity during which fertility declined. Caldwell et al. (1986) found that stress resulting from the 1980-83 South Indian Drought was associated with a preference for fewer but more educated children.

Ezra (1997) argued that the growing environmental stress and persistent food insecurity endured by Ethiopian communities over the past two decades stimulated changes in the demographic behaviors and attitudes of farming communities. He observed preferences for later age at marriage and smaller family size, a significant increase in acceptance rates of family planning services, actual reductions in fertility, increased migration (particularly of the youth) out of the communities, and the tendency by many farmers to be involved in non-farm income generating activities. It is argued that demographic transition is faster in ecologically degraded communities than in relatively stable ones.

However, in all of the above examples the fertility effects traceable to environmental causes were found to be relatively modest, and the results of studies of pre-industrial societies are not necessarily relevant to modern societies where many social, economic, and technological factors have changed and where there is greater potential for policy to mediate between environmental stress and demographic responses. Currently, no long-term projections explicitly take into account environmental feedbacks on fertility. However, in IIASA's probabilistic projections, the small probability of significant effects are implicitly included in the tails of the fertility distribution (Lutz et al 1996b).

5.2.3 Current projections

5.2.3.1 UN*

Historically, the medium projection in UN Revisions (which extend to 2050) has incorporated the assumption of universal convergence to replacement level fertility, with somewhat higher and lower levels assumed in the high and low variants. Recently, this approach was abandoned for countries in which fertility is currently below 2.1 (UN 1999d). This change in practice has been based on the observation that the number of countries with below-replacement fertility is large and increasing. By 1995, 44 percent of the world population lived in countries where fertility was at or below replacement level, including several countries in the developing world such as China, North and South Korea, and Thailand. In many of these countries low fertility has persisted for a decade or two. Furthermore, in more than 20 countries, including Italy, Spain, and Germany, fertility has fallen below 1.5 births per woman.

As a result, the medium variant of the 1998 Revision assumes that fertility in countries where it is below 2.1 in 1990-95 will remain below replacement level until 2050. Low fertility countries are divided into two groups: those with fertility in 1990-95 between 1.5 and 2.1, and those with fertility below 1.5. In the first group, fertility is projected to rise to 1.9, and in the second to 1.7, and remain constant thereafter (Note 9). However, in countries with fertility above 2.1 children per woman in 1990-95, the UN maintains its historical assumption that fertility will undergo a smooth decline to replacement level and remain constant thereafter.

The pace of fertility decline for currently high fertility countries is determined by setting a period in which fertility is assumed to reach its eventual level. This determination is made based mainly on the current level of and recent trends in fertility in each country, and a comparison to other countries with similar conditions. The choice of target year has changed little in recent UN Revisions. In currently low fertility countries, data more recent than the base period (1990-95) was used to extend fertility

* Based on Zlotnik 1999a, UN 1999a, 1999d

trends to the 2000-05 period. They were subsequently assumed to change at a constant rate until reaching their ultimate level.

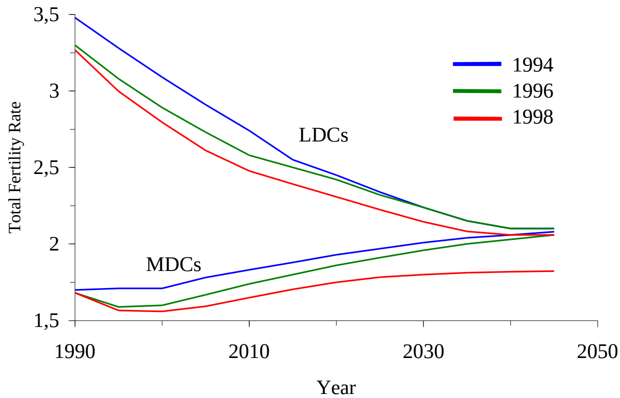
In the high and low scenarios, fertility in countries currently above replacement level was assumed to eventually stabilize at half a birth per woman above and below replacement, respectively. Fertility in countries currently below replacement level was assumed to stabilize at 0.4 births per woman above and below the level it achieved in the medium variant, respectively (Note 10). The pace of fertility change was adjusted so that currently high-fertility countries reached ultimate fertility levels in the same target period as in the medium variant. In low fertility countries, the pace of fertility change was held constant at a slightly greater rate than in the medium variant.

Once total fertility rates were determined for all countries in all periods, they were translated to age specific fertility rates. In countries where fertility is currently below replacement level, age specific rates are generally held constant. In currently high-fertility countries, age patterns are determined by interpolating between the estimated current schedule, and one of three model schedules (UN 1999d) for countries that have completed a fertility transition.

The UN has revised its estimates of current fertility and projections of future fertility over the past several projection cycles. Figure 2 shows projected fertility for MDCs and LDCs for the 1990-2050 period for the UN 1994, 1996, and 1998 Revisions. In 1996, the estimate of LDC fertility in 1990-95 was 3.3, nearly 0.2 births per woman less than the medium variant projection made in 1994 (which used 1985-1990 as the base period), and slightly less than even the 1994 low variant. This revision also lowered projected fertility over the next several decades. Between 1996 and 1998, the base period TFR was revised only slightly, but projected fertility was lowered further over nearly the entire projection horizon. The figure also shows that expectations for future fertility in MDCs have been lowered as well, particularly in the 1998 revision which discarded the assumption of an eventual rise to replacement level in these countries. The net differences for projected population totals in 2050 amount to more than 1 billion: projected population in 2050 dropped from about 10 billion in 1994 to less than 9 billion in 1998.

Due to these changes, the UN took the unusual step of producing updated long-term projections to 2150 based on the 1998 Revisions. The previous long-term projection had been produced just two years earlier, based on the 1996 Revision. Usually, long-term projections are produced approximately every ten years. Although the medium variant of the 1998 Revision no longer assumes convergence to replacement level, the medium scenario of the long-range projections has maintained this assumption. Thus in currently low-fertility countries, fertility is still below replacement level in 2050, but is assumed to rise to replacement level 5 to 25 years later depending on the region (UN 1999a). The reason for this choice appears to be to provide 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" (UN 1999a, 34).

Figure 2: *Total fertility rate for MDCs and LDCs according to the UN medium variant in 1994, 1996, and 1998.*



5.2.3.2 IIASA*

IIASA fertility scenarios are based on expert opinion on possible fertility levels in the period 2030-2035. Based on recent experience and the belief that the demographic transition is almost certain to continue, it is assumed that fertility in LDCs will continue to decline. Thus, even in the high scenario, which is based on the possibility that fertility transition is retarded or stalled, fertility in the period 2030-35 is projected to be lower than it is today. One exception is China, where the high variant assumes that fertility rises from 2.0 to 3.0, based on the possibility that the country's one-child policy could be relaxed and fertility might rise as a result. The second exception is Latin America, where it is assumed that fertility stalls in the region as a whole at 3.0 since there is evidence that such a stall has occurred in particular countries due to heterogeneous populations in which some segments are well advanced in the demographic transition while others have hardly started it.

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* Based on Lutz et al 1996b, Lutz 1995

Low-variant assumptions imply that fertility decline in LDCs, as has been the experience in MDCs, does not stop at a TFR of 2.1 but continues to decline, carrying countries into the range of sub-replacement fertility. The Central assumptions, derived by averaging High and Low variants, are assumed to represent the most likely case and result in slightly above replacement-level fertility in 2030-2035 in most LDC regions – substantially so in sub-Saharan Africa.

In MDCs, the IIASA high scenario assumes a return to replacement level fertility (or slightly above) by 2030-35 (Note 11). This scenario is taken to be representative of the systems view of fertility which argues for an inherent tendency of demographic systems to maintain themselves. The low scenario projects a fertility level of 1.4 in North America and 1.3 in the other developed regions, with central variants obtained by averaging high and low assumptions.

Fertility assumptions for all regions were extended into the future by assuming that in 2080-85, TFR would lie in the range 1.7 - 2.1 in the central scenario, depending on the population density of the region in 2030-35. The least densely populated region (South America) was assigned an eventual fertility of 2.1, and the most densely populated (South Asia) was assigned a level of 1.7. Fertility for other regions was determined by linearly interpolating between the values for these regions. High and low scenarios were assigned levels 0.5 above or below the central assumptions. Although there is some empirical evidence that high population density tends to induce lower fertility after controlling for other factors, IIASA demographers recognize that this procedure is still somewhat *ad hoc*. It is defended on the grounds that it represents an improvement over what they consider the shaky assumption of eventual replacement level fertility.

Fertility in all regions is interpolated linearly between assumptions for 2030-35 and 2080-85, and held constant beyond 2080-85. It is also interpolated between the base period (1990-95) value and 2030-35, although the high and low scenarios "open up" more quickly over the first five year period to correct for what was considered an unrealistically small range of uncertainty in the early periods that would have resulted from a strictly linear interpolation.

5.2.3.3 U.S. Census Bureau*

The USCB projects future fertility in each country based on a combination of expert judgment and statistical fits to past trends. Eventual fertility levels for each country are determined based on the judgment of regional experts. In general, where fertility is

* Based on USCB 1999, Peter Johnson (pers. comm.)

currently very low it is projected to rise, and where it is very high it is expected to eventually fall to about 2.0. Other countries generally converge to levels between 1.7 and 2.0.

If more than one historical data point for fertility exists, a logistic function describing a transition from an initial high fertility level to the assumed eventual level is fit to the data. Depending on the data and assumptions for a particular country, the eventual fertility level may or may not be reached before the end of the projection period in 2050. If no data are available, projections are made based on other countries with similar experience. Also, if eventual fertility is assumed to differ little from current fertility, a linear function may be used instead of a logistic.

The plausibility of the projections for each country is then evaluated by USCB demographers in light of recent population trends, socioeconomic trends, and population policies. Such factors as trends in age at marriage, the proportion of women using contraception, the strength of family planning programs, and women's educational attainment and participation in the labor force are considered. If the projection for a country is judged to be inconsistent with these trends, the logistic fit is adjusted until a projection considered to be reasonable is obtained.

As a final check, projected fertility for different countries are compared to make sure that differences in projections can be explained by known differences in the characteristics of each country. Age specific fertility rates in each year of the projection are derived by interpolating between current age specific rates and the rates for a "model" set derived from empirical data for populations that have already achieved the levels of fertility projected to be reached in the future.

5.2.3.4 Comparison

Figures 3a and 3b compare projected fertility over the period 1995-2050 for the ten largest countries according to the UN Medium variant and the USCB projection. It illustrates some of the differences between the assumptions made by the two institutions. For example, TFR is considerably higher in Nigeria according to the USCB over the entire projection period. The figure shows that this is primarily due to a higher assumed TFR in the initial period in the USCB projection (6.3 vs. 5.7); the two institutions project roughly equal rates of decline in this country thereafter. For Indonesia, both institutions assume the same fertility in the base period, but the UN projects a rapid decline to replacement level and constant fertility thereafter, while the USCB projects a slower but more sustained fertility decline, eventually falling to 1.8. For India, the UN again assumes a more rapid decline to replacement level than does the USCB, although in this case the USCB projection is in agreement on the eventual fertility level.

Figure 3a: *Total fertility rate projections for the ten largest countries according to the UN Medium variant (dashed lines) and the US Census Bureau (solid lines), for each five-year period between 1990 and 2050. USCB values two years into each five-year period are taken as representative of the average over the period.*

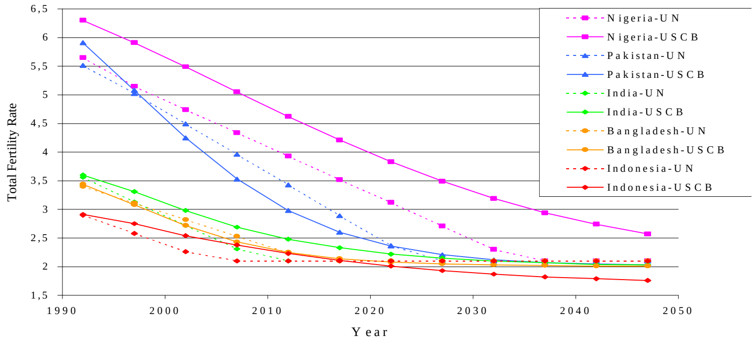
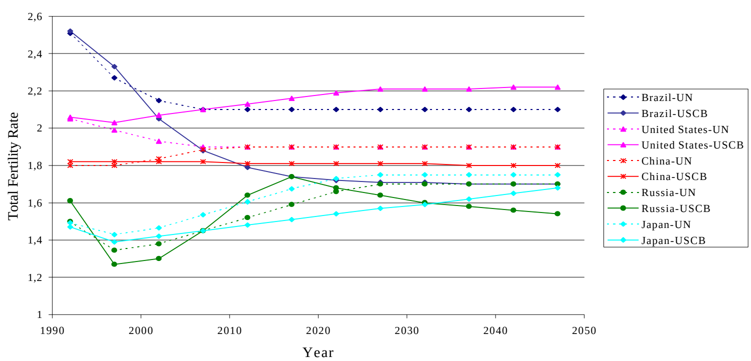


Figure 3b:



Differences between the two institutions' projections for Brazil and the U.S. are striking. In both cases, the UN and the USCB assume very similar fertility levels in the base period, but the UN projects a decline in U.S. fertility to below replacement level (1.9), while the USCB projects a rise to above replacement level (2.3). The situation is reversed for Brazil: the USCB projects a decline to substantially below replacement level (1.7), while the UN foresees a decline that stalls at replacement level.

Differences between institutions are small for China: the USCB assumes TFR remains essentially constant at 1.8, while the UN assumes a slow increase from 1.8 to 1.9. In Russia, both institutions agree on a current TFR of about 1.3, but the UN projects a rise to 1.7 while the USCB projects a more rapid rise to 1.7, then a fall to 1.5, thus ending up below the UN projection for 2050

5.3 Projecting future mortality

Mortality projections are based on projecting future life expectancy at birth for males and females, defined as the average lifespan of a child born today if current age-specific mortality levels were held fixed in the future. Life expectancy (like the total fertility rate), is a period measure, and does not reflect the actual experience of a particular individual. Nonetheless, it provides a useful summary of the prevailing age specific mortality rates to which a population is exposed at a particular time. Mortality projections must also specify how mortality is distributed over different age groups for both sexes, and how these distributions may change over time. For example, gains in life expectancy can come from declines in infant mortality rates, or from lower mortality for older age groups; changes in mortality at different ages, even if they have equal impacts on life expectancy, have different consequences for population growth and age structure.

5.3.1 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 impressive increases in life expectancy to levels that used to be considered a biological upper limit to the human life span. Assumptions about future improvements depend crucially on whether or not such a limit exists and how soon it might be reached. In developing countries where mortality remains high, future life expectancy will be determined by the efficiency of local health services, the spread of traditional (e.g., malaria) and new (e.g., AIDS) diseases, and the general standards of living and education. The gap in life expectancy between MDCs and LDCs has narrowed over the past 50 years, and is likely to narrow further unless the AIDS epidemic stalls further progress in a significant fraction of LDCs.

5.3.1.1 Life expectancy

In MDCs, 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 are a range of opinions on how long this trend can continue.

One point of view is that life expectancy in MDCs is unlikely to increase from its current level of about 75 years to much beyond 85 years. Some argue that this age represents an intrinsic (i.e., genetically determined), unmalleable limit to the human lifespan (Fries 1980). Therefore, improvements in mortality that do occur are likely to increase the chance of survival to the maximum lifespan, but not to extend the maximum itself. Others argue that while the intrinsic limit may be modifiable, in practical terms it is unlikely to be exceeded without unforeseeable medical breakthroughs (Olshansky et al 1990, Olshansky 1997, Harman 1991). 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. Since complete elimination of deaths from major fatal diseases such as heart disease, cancer, and diabetes would not extend life expectancy beyond 90, these dramatic reductions are considered unlikely to occur.

However, a second point of view is that substantial improvements in life expectancy due to reduced old-age mortality are possible. Data from several developed countries shows 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 (Vaupel 1997a, 1997b). In attempting to understand this trend, researchers are investigating the evolutionary basis for aging (Kirkwood 1997). Evolutionary biologists and biodemographers theorize that senescence is an inadvertent consequence of sexual reproduction. Genes responsible for lethal diseases that occur in post-reproductive years evade the influence of natural selection because, unlike genes associated with diseases earlier in life, they are passed on before they are expressed (Rose 1999, Olshansky et al 1998). Thus mortality rates inevitably rise beyond the reproductive period. Intriguingly, increases in mortality decelerate at older ages, not only in humans but in several other species as well (Vaupel 1997c). As of yet, 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. For example, Vallin and Caselli (1997) show that if life expectancy were to increase to 150 years over the next two centuries, global population will stabilize at a level twice as high as it would if life expectancy did not exceed 85 years. Short of this more extreme outcome, a recent review (NRC 2000) concluded that future medical advances and the possibility of breakthroughs supports the likelihood of continued steady gains in life expectancy in industrialized countries.

In LDCs, possible limits to the lifespan are not as relevant to projections since life expectancies are lower and mortality is not as concentrated at the oldest ages. Life expectancy in LDCs increased from about 40 in the 1950s to just over 60 in the early 1990s (UN 1999c), a remarkable achievement driven mainly by reductions in mortality due to infectious disease. Regional progress was variable, with the slowest gains in sub-Saharan Africa and the fastest in China, where life expectancy reached 68 in the 1990s. Projecting mortality in LDCs is made difficult by the relative scarcity and poor quality of data on current and past trends. In addition, the future course of the AIDS epidemic could substantially affect mortality in many countries, especially in sub-Saharan Africa where HIV prevalence rates are especially high.

Life expectancy is an explicit assumption of each projection. The assumptions used by each institution are discussed below.

5.3.1.2 New epidemics (HIV/AIDS)

The impressive gains in life expectancy in the LDCs over the past several decades has in many countries been slowed or, in the most serious cases, even reversed due to the impact of AIDS. Sub-Saharan Africa has been most affected. For example, in Botswana life expectancy has dropped from about 63 years in the late 1980s to below 50 in the late 1990s, and Zimbabwe has seen life expectancy fall from 57 to 44 years over the same period (UN 1999c). By subjecting members of the most economically active and productive groups to a premature death, AIDS is imposing an enormous economic and social toll on the continent (Ainsworth and Over 1994).

The effects of AIDS on population growth and age structure could be significant in affected countries. The U.N. (1999b) estimates that for the 29 African countries in which it adjusts its projections to account for AIDS, population size will be on average 8.1 percent lower in 2015 than it would be without any deaths from AIDS. This represents a 5.4 percent difference in the population of Africa as a whole. In the nine most affected countries, the impact is projected to be nearly 15 percent.

Independent simulations suggest that impacts in some countries may be even greater. Population size may well decline in Botswana (Sanderson 1998), where the HIV prevalence rate is estimated to be well above 30%. Moreover, the age structure will become severely distorted and 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 AIDS on the population of Africa as a whole will be moderate if exceptionally high HIV prevalence rates exist only in Botswana and a few other countries with special conditions. If high prevalence rates turn out to be more widespread, AIDS could have a significant impact on African population dynamics.

For selected countries, AIDS mortality is taken explicitly into account by altering assumptions. These are identified below.

5.3.2 Feedbacks: Carrying capacity and health

Environmental change has had important direct or indirect effects on mortality in the past. For example, climate change is likely to have contributed to the collapse of the Classic Maya culture in Yucatan (A.D. 800–1000; Lutz et al 1996b) and the decline of the Easter Island civilization in the 18^{th} and 19^{th} centuries (Brander and Taylor 1998). Yet these massive disruptions occurred in a context of extremely limited technical capacity to respond to change; their relevance to future environmental change is unclear. The most frequently discussed possibilities for future effects center around the idea of carrying capacity 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 strong enough to be an important determinant of future mortality trends (NRC 2000).

The concept of carrying capacity has its roots in ecology and the population biology of non-human 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 energy, agriculture, water, mineral resources, disease, and biological diversity. No consensus on the human carrying capacity has emerged; on the contrary, the range of estimates has widened over time (Cohen 1995).

There are at least three reasons that carrying capacity is not considered in long-term population projections. 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 be strongly dependent on which factor or factors were assumed to be limiting, as well as on the how thinly any one factor had to be spread to begin to exert its limiting influence. For example, while food is often taken as a limiting factor, the maximum population that could be fed would depend on, among other things, the typical diet, agricultural productivity (which itself would depend on technology, agricultural research, irrigation, etc.), the allowable fraction of land usable for agriculture (which itself would depend on the value attached to biodiversity and the existence of wilderness), and so on. In addition, a factor that may be limiting in one region may be available in excess in another, and therefore the possibility of inter-regional trade would have to be considered as well.

Second, even if the relevant factors could be agreed on, it may be too difficult to project the future evolution of those factors to be of use in population projections (Keyfitz 1982). 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 (Cohen 1998). Thus, even projections contingent on projected developments in other areas would be highly uncertain.

Although no long-term projections routinely take carrying capacity into account, some researchers (Cohen 1998, NRC 2000) have argued that it may be worth considering limiting factors when projecting population, especially over long time horizons, in particular locations where resources are especially limiting and potential for trade is low, or when the intention is to warn against an undesirable outcome, to describe a path to a desirable state, or to analyze the consequences of some hypothetical relationship between demographic factors and constraints. Lutz et al. (1996) examined the potential demographic consequences of an assumed carrying capacity of 2.5 billion for Sub-Saharan Africa as an illustration of how such an exercise might be carried out. They demonstrated that if a catastrophe due to war, famine, disease, or some other means resulted in a sudden 20% increase in mortality and left fertility unchanged at a high level, the population of the region would regain its 20% loss within 10-15 years. However, the 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 more detailed accounting of the effects of a catastrophe than is commonly assumed.

In addition, some projections implicitly take environmental feedbacks into account. For example, while the UN projections do not consider possible feedbacks (UN 1999a), the IIASA methodology for developing probabilistic projections directed experts to consider ecological catastrophes in their estimates of confidence intervals for future vital rates. Thus the tails of the probability distributions for these rates can be considered to account for the possibility of strong feedbacks from environmental changes.

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 lead to the spread of infectious diseases beyond their traditional boundaries of occurrence or contribute to the spread of new diseases. There is also concern about the health consequences of the potential for more frequent and severe heat waves and other extreme events.

The spread of infectious diseases could be exacerbated by climate change as warmer temperatures extend the ranges and accelerate the lifecycles of mosquitoes and other disease vectors. Several studies have examined the effect of interannual climate variability on diseases such as malaria, schistosomiasis, sleeping sickness, dengue, and yellow fever in order to characterize links between climate variables and infection. Loevinsohn (1994) associated a 1 degree Celsius increase in the average temperature in Rwanda in 1987 with a 337% 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 Nino-Southern Oscillation (ENSO) phenomenon, which periodically disrupts climate in particular regions around the world (Epstein 2000). Colwell (1996) attributes outbreaks of cholera in Latin America and Bangladesh in the early 1990s to ENSO events as well, although she noted that the epidemics behaved differently in Latin America according to prevailing levels of poverty, health education, sanitation, and other risk factors. Other studies have shown that one of the prime carriers of dengue and yellow fever – the *Aedes aegypti mosquito* – has extended its range to higher elevations in such diverse regions as Costa Rica, Colombia, India, and Kenya (Epstein 1999).

If climate change leads to an increase in the frequency and/or intensity of extreme events, health conditions will be affected, particularly in developing countries (International Federation of the Red Cross and Red Crescent Societies 1998). For example, the intense precipitation and flooding associated with hurricanes often spawns clusters of disease outbreaks, including cholera (a water borne disease), malaria and dengue fever. Severe drought often triggers migration, which can facilitate the spread of infectious diseases (McMichael et al 1996).

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, they are not explicitly considered in producing long-range population projections.

5.3.3 Current projections

5.3.3.1 UN*

The UN projects a single mortality path for all scenarios of its population projections to 2050. In the 1998 Revision, it assumes that all countries will eventually reach a maximum life expectancy of 87.5 years for males and 92.5 years for females. The pace of change is determined by assigning one of three models of change in life expectancy to each country (fast, medium, and slow change) based on recent experience and on the idea that improvements in life expectancy will slow as life expectancy grows. Countries may be assumed to switch from one model to another in 2025. No country actually reaches the maximum life expectancy by 2050, and only North America reaches this maximum by 2150 in the long-term projections, but it is the implicit end point of all paths. The projected life expectancies are translated into age-specific mortality rates by interpolating between the estimated current life table and a model ultimate life table for each region.

The impact of HIV/AIDS on mortality is explicitly taken into account for 34 countries—29 of them in Africa—where prevalence rates are above 2%, plus Brazil and India where prevalence was still low but had a large number of infected persons (UN 1999b). Models are used to estimate the annual incidence of the disease (i.e., annual number of newly infected individuals) based on recent estimates of prevalence (i.e., the total number of HIV-positive individuals at particular points in time). The annual number of deaths from AIDS is then estimated 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.

A recent revision to the UN methodology was the addition of five-year age groups between 80 and 100 years of age. Previously, the oldest age group had been the open-ended 80+ group. Currently, it is the 100+ age group. The addition of these groups was made difficult by the scarcity of mortality data for the elderly.

UN projections of life expectancy have changed little in recent years, with a slightly less optimistic outlook for LDCs (see Figure 4). The projection of a rise in LDC life expectancy from its current level of about 62 years to 75.5 years in 2050 is about 1 year less than the rise to 76.4 years envisioned in the 1994 revision. This change is primarily due to new data on the extent and implications of HIV/AIDS mortality.

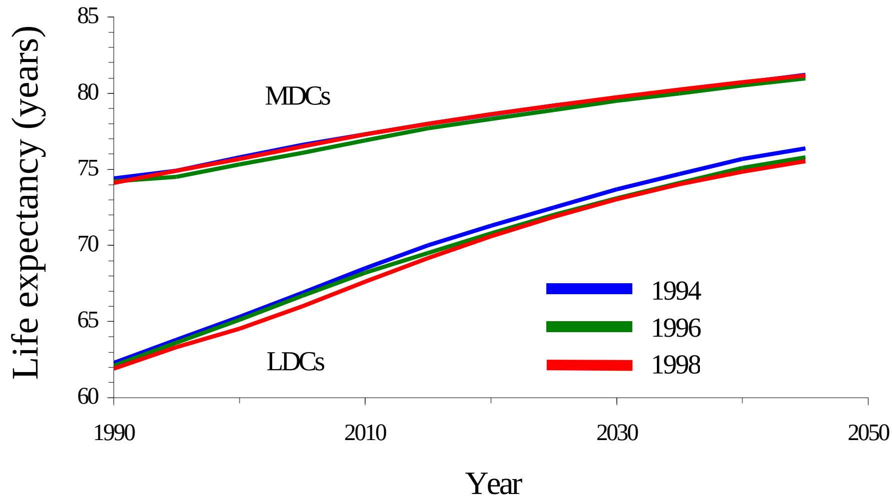
Over a longer time period, the UN has consistently revised upward its assumptions on the limits of life expectancy (Bucht 1996). For example, in 1973 it was assumed that the highest life expectancies would be 77.5 years for women and 72.6 years for men, as

* Based on Zlotnik 1999a, UN 1999a, 1999d

compared to 87.5 and 82.5 years in the 1996 Revision. In the most recent long-term projections, life expectancy can rise as high as 92.5 years.

The UN long-range projections include for the first time scenarios in which mortality is assumed to remain constant after 2050, for the sake of comparison to its scenarios with continued declines in mortality.

Figure 4: *Projected life expectancy at birth in MDCs and LDCs according to the UN medium variant in the 1994, 1996, and 1998 revision.*



5.3.3.2 IIASA*

Unlike the UN, IIASA uses three different scenarios for mortality change. The low mortality scenario projects improvements in MDCs of three years per decade, slightly greater than recent trends in Western Europe and North America, but slower than recent improvements in Japan. The high scenario projects increases of one year per decade in developed country regions. The central scenario, as an average of the high and low, assumes a two-year per decade increase in life expectancy. An exception was made for European parts of the former Soviet Union, where the low and high scenarios were set to four and zero years per decade increases; the latter assumes a continuation of difficult socioeconomic conditions that have been associated with a recent decline in life

* Based on Lutz et al 1996b

expectancy in the region, and the former assumes a recovery and adoption of more Western lifestyles.

In LDC regions, life expectancy is also assumed to increase at one, two or three years per decade in the high, central, and low mortality scenarios, with several exceptions. For sub-Saharan Africa, the range was extended to improvements of four years per decade in the low mortality case to allow for the possibility of a process of catching up with other regions of the world, and a decline of two years per decade in the high mortality case to take into account the possible impact of AIDS and potential food shortages. The central scenario therefore assumes slow improvements of one year per decade. South Asia and Pacific Asia are also assigned a wider range to take into account uncertainty associated with AIDS (zero, two and four years per decade in the high, central, and low mortality scenarios). In South Asia and China, life expectancy is assumed to increase more rapidly for women on the assumption that differential treatment of girls in these societies, which has probably depressed female life expectancy, eases in the future. Finally, in North Africa and the Middle East, the range of possible mortality changes was widened to 0.5 - 4 years to account for their greater potential for improvement.

To define current age distributions of mortality, IIASA projections use observed age-specific patterns of mortality for developed country regions, and UN model life tables for developing countries. In regions significantly affected by AIDS, adjustments were made to account for assumed age patterns of AIDS mortality. Age patterns of mortality were held fixed through time, and scaled to changing life expectancies.

5.3.3.3 U.S. Census Bureau*

The USCB 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. No country reaches the maximum life expectancy by the end of the projection period in 2050.

Age-specific mortality rates in each year of the projection are derived by interpolating between current age specific rates and the rates for a "model" set

* Based on USCB 1999, Peter Johnson (pers. comm.)

representative of low mortality conditions. In 28 countries where the risk of death from AIDS is significant, mortality is explicitly adjusted by modeling the spread of HIV infection and the development of AIDS. Countries where the urban low-risk population had reached or would soon reach a seroprevalence rate of 5% were selected (USCB 1999). They consisted of 21 countries from sub-Saharan Africa and seven from elsewhere (Guyana, Burma, Haiti, Cambodia, Honduras, Brazil and Thailand; Note 12). The model projects the course of the epidemic through 2010 based on current and historical data. Growth in HIV infection is assumed to peak in that year, and AIDS mortality is assumed to decline to zero by 2060.

5.3.3.4 Comparison

Figure 5 compares projected life expectancy over the period 1995-2050 for the ten largest countries according to the UN Medium variant and the USCB projection. In most of the 10 countries shown, assumptions regarding mortality are similar between the two institutions. There are several exceptions. In Brazil, the USCB projects a decline from 67 to 63 over the first 15 years, and then a rise to 78 by 2050. In contrast, the UN assumes a steady rise from 66 to 76 over the same period. Similarly, in Nigeria the USCB projects a decline from 53 to 48 over the next 15 years, followed by a rise to 69 by 2050. The UN projects a sustained rise from 50 to 69 over the same period. As a result, the USCB life expectancy projections for these two countries are substantially below that of the UN for most of the projection period. These differences are due primarily to assumptions regarding the impact of HIV/AIDS (Note 13). In Pakistan, the USCB projection is consistently below the UN projection by 2-4 years throughout the projection period. Most of this gap is due to a difference in the assumption regarding current life expectancy, which is lower by about 4 years in the USCB projections.

Figure 5a: *Life expectancy projections for the ten largest countries according to the UN Medium variant (solid lines) and the US Census Bureau (dashed lines), 1995-2050.*

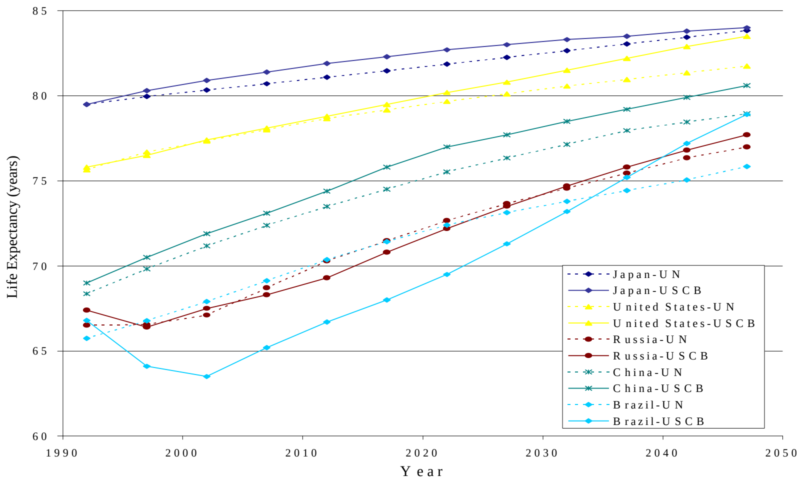
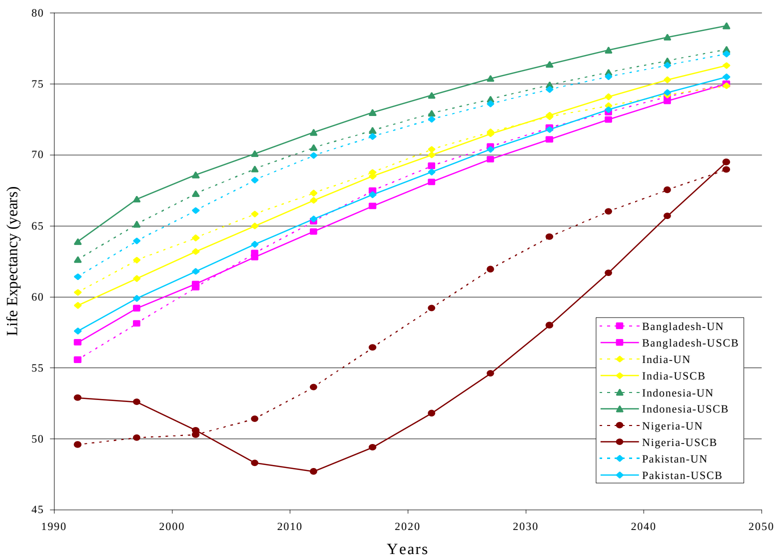


Figure 5b:



5.4 Projecting future migration

Future international migration is more difficult to project than fertility or mortality. Migration can be volatile since short-term changes in economic, social, or political factors often play an important role. In addition, since no single, compelling theory of migration exists, projections are generally based on past trends and current policies; however, data on historical migration are sparse.

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, net international migration accounted for nearly half of the population growth rate in MDCs (UN 1998b, ch. 1). In particular regions and countries, effects are even more striking. The population of Western Europe grew at an annual rate of 0.6 % over the period 1990-95, and migration accounted for over 80% of that rate. Migration also accounts for substantial fractions of the growth rates 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 undertaken an exercise to project 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 population size, the size of working-age (15-64 years) population, and the ratio of working-age to old-age population (or support ratio) (UN 2000a). Results showed that the size of the required migration streams were implausibly large compared to current net immigration flows and to the size of the receiving populations, especially in the case of migration needed to maintain the support ratio (PDR 2000).

In contrast, migration had only a small negative impact on the 1990-95 growth rate of LDCs considered as a whole. However, migration within developing regions played an important role in growth at the national level. For example, a third of Mozambique's nearly 4% annual growth rate was due to in-migration, mainly the return of refugees from Malawi. Similarly, while Guinea grew at nearly 6% per year, its growth rate would have been 4% without migration, which consisted largely of refugees from Liberia.

5.4.1 Conceptual basis for projections

Projections of international migration generally begin with consideration of current and historical trends (Zlotnik 1998, NRC 2000). For example, most projections foresee continued net migration into traditional receiving countries such as the U.S., 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 migration trends. For example, population growth rates in sending regions are not a good indicator of emigration flows. In general, correlations between rates of natural increase in developing countries and levels of emigration to developed countries have been weak or nonexistent (Zlotnik 1999b).

There are a number of theories that attempt to explain migration from different disciplinary perspectives (Massey et al 1998, UN 1998b, ch. 8). Economic approaches see international migration mainly as a mechanism for redistributing labor analogous to the process of rural-urban migration within countries (e.g., Todaro 1976). From a macroeconomic perspective, labor flows are assumed to be driven by wage differences, implying that populations will tend to redistribute until wage rates differ only due to migration costs. Individuals decide to migrate based on weighing the estimated benefits against the costs of moving. Therefore, the choice of destination will depend on where they perceive their skills to be most productive. The socio-economic environment of the country of origin clearly plays a role as well, however. For example, migrants usually do not belong to the lowest income classes in their countries of origin, and emigration appears more likely to occur in countries that have already attained a certain level of development and are advancing in the development process rather than in countries stagnating at low levels of development (UN 1998b, ch. 8).

The basic neoclassical model emphasizing the labor market is generally regarded as an important component of explanations of migration, but 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 are also strongly influenced by family or household demand for insurance. By diversifying family labor, households can minimize risks to their well being (Stark 1991).

A different approach theorizes that demand for migrant labor is inherent to the economic structure of developed countries (Piore 1979). Reasons include an occupational hierarchy that requires the existence of a low-wage, low-skill class to maintain relative status; bifurcated labor markets in which one class of jobs are unstable and unskilled; and the shrinking number of native workers, historically women and teenagers, willing to accept such positions.

Other 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 (Zolberg 1981). 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) (Martin and Widgren 1996). In addition to the factors evoked by the theories discussed above, others might include the need to flee life-threatening situations, environmental change (see below), the existence of kin or other social networks in destination countries, the existence of an underground market in migration, and income inequality and changes in cultural perceptions of migration in sending countries that are induced by migration itself (Massey et al 1993, UN 1998b).

Projections of net migration are incorporated into all population projections, as described below.

5.4.2 Feedbacks: Environmental refugees

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 (El-Hinnawi 1985). However, there is wide disagreement on the relevance of environmental change to migration (Suhrke 1994). At one end is the view that environmental conditions are just one of many "push" factors influencing migration decisions (MacKellar et al 1998). 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. It also acts in concert with other factors, and therefore its relative role is difficult to isolate.

At the other end lies the view that deteriorating environmental conditions are a key cause of a significant number of migrants in developing countries (Myers 1997, 1995; Jacobsen 1988, El-Hinnawi 1985). While other 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. Myers (1995) defines environmental refugees as "persons who can no longer gain a secure livelihood in their traditional homelands because of environmental factors of unusual scope, notably drought, desertification, deforestation, soil erosion, water shortages and climate change, also natural disasters…" and who "feel they have no alternative but to seek sustenance elsewhere." Others have argued that the term "refugee", with its associated image of human misery and chaos, overstates the case. The United Nations High Commission on 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 of a particular social group or political opinion" (UN 1951). Many African and Latin American states have extended the definition to include people who have fled from their homeland to escape from generalized violence, internal conflict, and serious disturbances to public order (UN 1998b, ch. 5). 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, while migrants move voluntarily and are in a much stronger position in their new residence than refugees (MacKellar et al 1998). 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 (Suhrke 1994).

The debate is more than academic. On the one hand, refusal to accept the "refugee" terminology has been equated with a refusal to recognize the issue as an important concern (Ramlogan 1996); on the other, the spread of the environmental refugee concept has been claimed to risk distracting attention from the pressing issues of refugees as traditionally defined (Suhrke 1994).

The degree to which environmental migration is relevant to long-term projections depends in part on the anticipated magnitude of the population movements. Myers (1995) estimates that environmental refugees (by his definition) currently number at least 25 million (over half of them in Sub-Saharan Africa), a figure that is roughly equal to the number of refugees and displaced persons as traditionally defined (UN 1998b, ch. 5, Note 14). In comparison, there are an estimated 125 million international migrants, i.e., people living in a country other than the one in which they were born (UN 1998b; Martin and Widgren, 1996). Myers predicts that the number of environmental refugees is likely to double by 2010, and could swell to 200 million by 2025 due to the impacts 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 any of the long-term projections. For the IIASA and UN long-range projections, which are based on regions consisting of several countries, much of the international migration would be masked as well. In addition, if environmental migration occurs in the future, its relevance compared to other factors driving migration, such as economic imbalances, must be weighed before concluding it is important to long-range population projections.

5.4.3 Current projections

5.4.3.1 UN[*]

For the purposes of projecting net migration, the UN divides countries into three broad groups: those projected to have zero net migration at all times; those projected to have non-zero net migration in the short to medium term, but zero migration thereafter; and those projected to have nonzero migration throughout the projection period of the 1998 Revision. This represents a significant break from previous Revisions, which assumed that migration fell to zero everywhere in 2025. The first group comprises about a quarter of all countries and areas, and includes countries in which in-migration and out-migration currently is not significant. The second group is much larger and includes countries that have been involved in flows of forced migrants, those that have a history of emigration or net out-migration but have not been experiencing large flows recently, and those that do not have such a history but have been experiencing significant net migration recently. The third group includes the traditional countries of immigration (Australia, Canada, and the U.S.), countries with a recent experience of net in-migration (Russian Federation and Germany), and traditional sources of migrants (Algeria, China, India, Mexico, the Philippines, etc.).

For its long-range projections, the UN considers migration too uncertain to project and therefore assumes that net migration is zero in all regions beyond the time horizon of the shorter term projections produced for the 1998 Revision (UN 1999a).

5.4.3.2 IIASA[**]

The IIASA migration scenarios are devised by determining a constant annual migration level for each region for the high scenario. In the low scenario, zero net migration is assumed. The central scenario is defined as the average of the high and low. Although migration streams will almost certainly vary in the future, constant values were assumed to be the most reasonable approach given the potential for volatility driven by unpredictable policy changes. 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 scenario, the traditional receiving regions continue to absorb large migrant flows of the roughly the same magnitude as recent trends (e.g., 1

[*] Based on Zlotnik 1999a, UN 1999a

[**] Based on Lutz et al 1996b

million annually to North America, 500 thousand to Western Europe, 175 thousand to Pacific Asia). The age patterns of migrant streams are based on model migration schedules from Rogers and Castro (1981).

5.4.3.3 U.S. Census Bureau*

For countries in which migration currently has an insignificant impact on its growth rate, future migration is often assumed to be zero. For countries with significant migration, future migration is often held constant at current levels into the near future, and then is assumed to diminish to zero in the medium to long term, with the timing of these changes varying from country to country. Age and sex compositions of migration streams are based on current data or on data from similar countries. Migration flows are adjusted so that out-migration is nearly equal to in-migration for the world as a whole. A small imbalance may remain, although it has a negligible effect on results.

6. Projection outcomes

Clearly, given the difficulties of establishing baseline data and the inherent uncertainty in projecting trends in vital rates, there is the potential for different population projections to produce widely varying population sizes, age structures, and distributions. An examination of projections from various institutions shows that results do indeed span a wide range; however, there are some similarities between central or "most likely" projections and also between plausible ranges of population size as projected by different institutions.

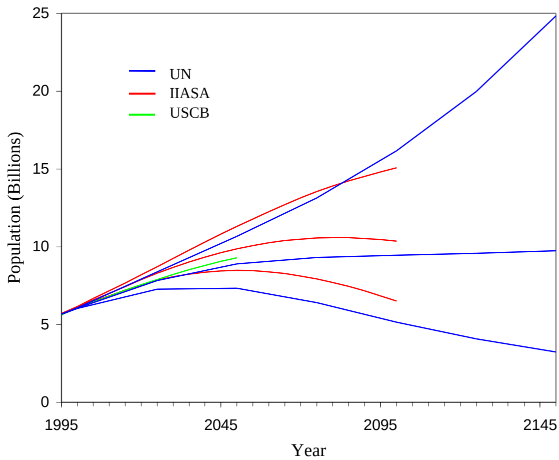
6.1 Population size

Figure 6 shows a summary of global population projections from the UN, IIASA, and the U.S. Census Bureau. The central or "most likely" scenarios from these institutions are similar in some respects, differing by about 10% in 2050 and 9% in 2100. The UN projects the least amount of growth, reaching 8.9 billion in 2050. IIASA projects the most, reaching 9.9 billion in the same year, and the USCB projects an intermediate figure of 9.3 billion. In the longer term, IIASA projects a global population of 10.4 billion in 2100 that has already begun to decline from a peak of 10.6 billion in 2080. In contrast, the UN projects a somewhat smaller population of 9.5 billion in 2100, but one

* Based on USCB 1998

that is still growing slowly (reaching 9.7 billion in 2150, the end of the projection period).

Figure 6: *Global population projections. High, central, and low projections from the UN and IIASA, and the US Census Bureau projection. The high and low scenarios from IIASA are the Slow and Rapid Demographic Transition scenarios, respectively.*



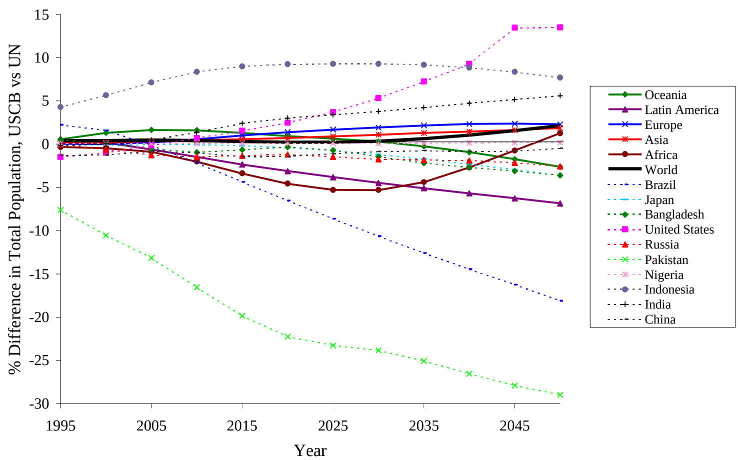
One noticeable difference is that the IIASA projections are significantly higher than the projections of either the UN or the USCB, particularly in the short-term. For example, the IIASA Central scenario is indistinguishable from the UN High scenario until after 2030, while the UN medium scenario closely tracks the IIASA Rapid Transition scenario until 2040 or so. Most of this difference is likely due to the higher levels of fertility in developing regions in the base period used in the IIASA projections, which were produced several years before the significant downward revisions in these data were made by the UN.

In the long term, the UN High and Low scenarios span a somewhat wider range than the IIASA scenarios. For example, the UN projects a global population of 5 to 16 billion by 2100, based on its Low and High scenarios, while IIASA projects a range of 6.5 to 15 billion based on its Rapid and Slow Demographic Transition scenarios. Because these scenarios assume that fertility and mortality are correlated, the range of future population sizes is diminished since low fertility is offset somewhat by low mortality, and high fertility by high mortality. If a central mortality scenario is used across all fertility scenarios, as is the practice of the UN, the IIASA range expands to 5 to 19 billion.

6.1.1 Regional and national comparison

Projections of global population growth tend to differ less across institutions than projections for smaller regions, since disagreements tend to cancel when regional projections are aggregated to global totals. Figure 7 compares the UN medium scenario to the US Census Bureau projection for the world, major regions, and for the ten largest countries. The largest percentage differences between the two projections tend to be for individual countries. For example, the USCB projects a significantly smaller population for Pakistan than does the UN – nearly 30% smaller than the UN projection by 2050. This is partly due to an 8% smaller assumed population in 1995, which is then compounded by a lower assumed future fertility path (see Figure 2) and a lower life expectancy path (see Figure 4). The USCB also projects significantly smaller population of Brazil, again due to lower assumed future fertility and life expectancy. Whereas the USCB tends to project smaller populations than the UN for these countries, in some instances their projections are higher than the UN's. For Indonesia, the USCB projects a population that approaches 10% larger than the UN projection by 2025. This is due in part to a larger assumed initial population in 1995 and in part to a higher assumed fertility over the first few decades of the projection, as well as to higher assumed life expectancy. The USCB projection for the United States is more than 10% larger than the UN projection in 2050 due mainly to a higher assumed fertility.

Figure 7: *Percent difference in population size between the USCB projection and the UN medium variant for the ten largest countries (dashed lines) and the world and selected major regions (solid lines), 1995-2050. Values below zero indicate that the USCB projects a smaller population size than the UN.*



In contrast, differences between projected sizes of regions, which aggregate many countries together, tend to be smaller. For example, projections of population for the world, Europe, Asia, and Oceania differ by only a few percent over the projection period. Differences in Africa are larger, approaching 5% around 2025, and there is a growing difference in the projected population of Latin America (more than 5% by 2050).

In some cases, agreement in projections of population size can mask large differences in underlying assumptions with offsetting effects. For example, projections of population growth in Nigeria differ very little between institutions. However, as demonstrated in Figures 2 and 4, this masks large offsetting disagreements in projected fertility and mortality.

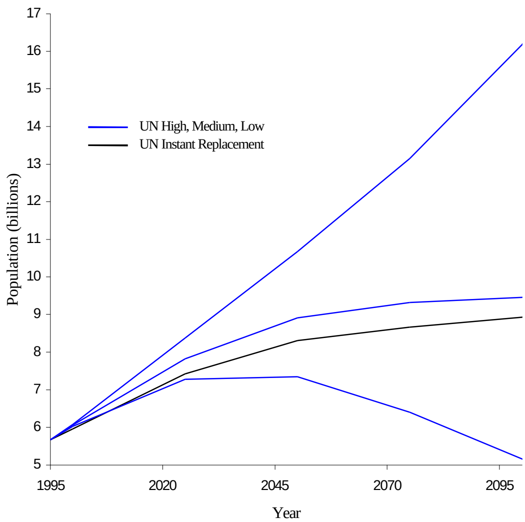
6.1.2 Momentum

Projections across institutions or across different scenarios from the same institution differ less in the short term than in the long term because of shared baseline data and the phenomenon of population momentum. Momentum refers to the growth that is built-in to the young age structure of growing populations: in a young population, even if fertility falls sharply, the numbers of mothers will continue to increase for a generation as the larger young cohorts age into their reproductive years (Keyfitz 1971). As a result, growing populations will continue to grow for some time 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 rise instantly to replacement level, population size would decline for some time.

Figure 8 illustrates the phenomenon of momentum at the global level. In the UN instant replacement level scenario, in which each cohort exactly replaces itself, population grows from 5.7 billion in 1995 to 7.4 billion in 2025 due to momentum alone. Momentum decreases uncertainty in population size in the short term because the next generation of reproductive-aged women has already been born. Thus differences between projections in the number of births over the short term arise primarily from differences in projected fertility rates, and not from projected numbers of women of childbearing age. For example, as shown in the figure, the UN Low and High scenarios project a global population of 7.3 to 8.4 billion in 2025. This range of just over 1 billion is far smaller than the range of 11 billion the scenarios produce in 2100, after the effects of momentum have faded.

Bongaarts and Bulatao (1999) offer a simple means of calculating the momentum inherent in currently high-fertility populations, and of projecting long-term population size without resorting to the cohort-component method, assuming fertility stabilizes at replacement level. While useful for communicating a fundamental feature of population dynamics, the momentum concept is less useful to projecting future population size if eventual fertility is not at replacement level, or if current fertility is below replacement level.

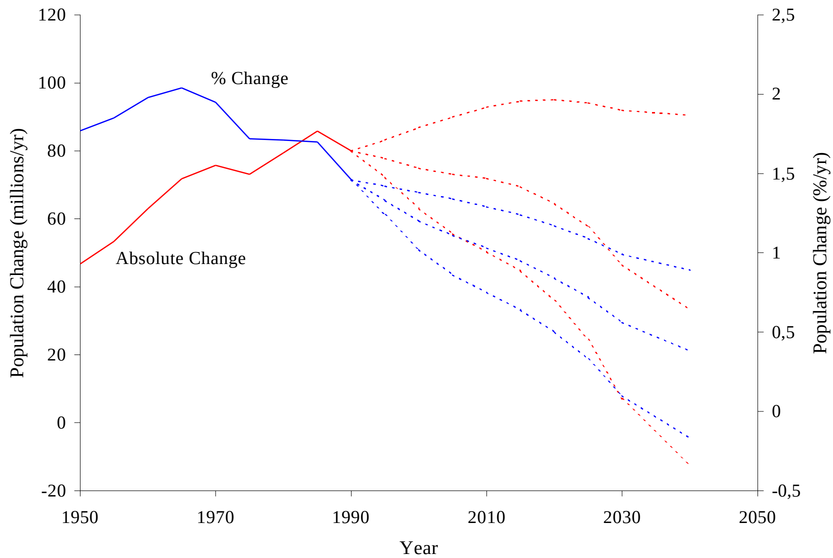
Figure 8: *Population momentum. The High, Medium and Low scenarios compared to the instant replacement level scenario from the UN Long-Range Projections.*



6.1.3 Absolute vs. relative growth

Despite the significant momentum in the current global population, growth over the next 50 years is still surprisingly uncertain. Using the UN 1998 Revision as an example, Figure 9 shows the implications of current global population projections for growth rates and absolute additions to the population, along with the historical trends in these figures since 1950. 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 1.5 %/yr to 0.4 %/yr by 2050 in the central scenario. The high and low scenarios show that the plausible range for these figures is -0.2 to +0.9 %/yr 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 after 2030.

Figure 9: *Annual absolute and relative population growth according to UN estimates and projections for low, medium and high scenarios.*

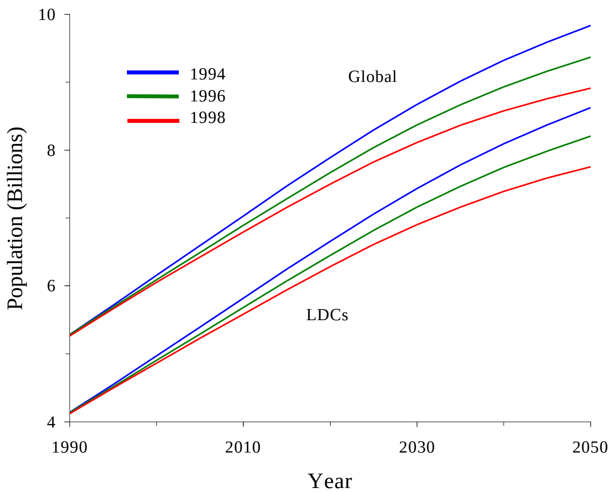


The absolute growth in population peaked in the late 1980s at about 86 million per year, and in the central scenario will remain above 60 million per year until 2020 and will decline more steeply thereafter. The projected drop-off in absolute growth is not as great as the drop-off in percent growth since population size is growing over this period. The projected range of population increments is very large: in the high scenario, annual growth increases to 95 million per year before beginning a slow decline, while in the low scenario it falls off steeply to zero in the 2030s. Thus, the UN 1998 projections cannot say with confidence whether global population will be declining or growing by more than 90 million per year 50 years in the future.

6.1.4 Recent UN revisions

Figure 10 shows the progressively slower population growth projected by the 1994, 1996, and 1998 Revisions from the UN. Projected population in 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 stemmed from a lower projected LDC population size, and this in turn was due primarily to lower projected fertility in LDCs. This was due first to a lower estimate of current fertility levels in LDCs, and then to a further downward revision of projected fertility (see section 5.2 on projecting future fertility).

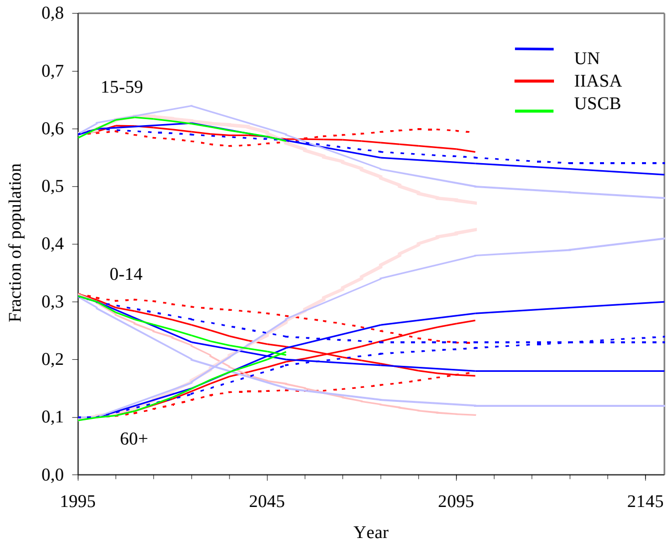
Figure 10: *Projected global and LDC population according to the UN 1994, 1996, and 1998 Revisions.*



6.2 Age structure

Momentous changes in age structure are clearly in store. Figure 11 shows that while in 1995 the global population below age 15 was about three times the size of the population above age 60, the proportion aged 60+ is projected to swell in all scenarios while the proportion below age 15 shrinks. For example, based on the UN Medium and IIASA Central scenarios, the proportion aged 60+ is likely to surpass the proportion below age 15 by the middle of the 21st century (2045 to 2060). The range of uncertainty in the relative sizes of these age groups is high, however. Based the high and low scenarios from these institutions, the 60+ age group could overtake the below-15 age group as early as 2030 or as late as well beyond 2100. 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 to 22% of the total population in 2100. Similarly, while the proportion aged 60+ will grow, it could reach 18 to 43% of the population by the end of the century.

Figure 11: *UN, IIASA and USCB global population projections by age groups as proportions of total population. Results of low, medium, and high projections are indicated by dotted, solid, and dashed lines, respectively.*



The 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 aging trends, even while it narrows the range of future population size.

The proportion of the population aged 15-59 is projected to be somewhat more stable across scenarios and across time. Figure 11 shows that this proportion is just under 60% in 1995 and falls to 47 - 59% in all IIASA scenarios by 2100, and 50-55% in the UN scenarios in the same year.

6.3 Distribution

6.3.1 Urbanization

Currently, the only institution that produces projections of urban and rural population growth at the global scale is the UN, which 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 (UN 1998c, 2000b; Note 15). According to this scenario, the world is expected to continue a historical trend of increasing urbanization. In 2000, 47% of the global population is estimated to reside 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% of the total population. In MDCs, the urban population is projected to rise from about 76% of total population in 2000 to 84% by 2030. In LDCs, the urban proportion rises more steeply from 40% currently to 56% in 2030, narrowing the gap in urbanization levels between MDCs and LDCs. Nonetheless, the projected level of urbanization in LDCs in 2030 will be similar to the level reached in MDCs in the 1950s. There is clearly scope for a continued shift in population from rural areas to urban centers beyond 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 developing country regions are expected to begin to decline within a few decades.

One difficulty in projecting urban population from historical data is the wide variety of definitions of "urban" employed by different countries (UN 1998c). Many countries define urban areas in administrative terms, for example according to the kind of authority under which an area falls. Often, population size or density of an area is employed as a key criterion. Additionally, characteristics such as the proportion of labor force employed in non-agricultural activities or the availability of urban facilities such as water or sewer systems may be used. The UN does not impose a single definition of urban across all countries. Rather, while it adjusts data to maximize consistency of definitions over time within countries, the UN adopts each country's own definition.

The projection methodology is based on extrapolating the rate of change of the ratio of the urban population of a particular country to its rural population. Historical data shows that this "urban-rural growth difference (URGD)", so named because the rate of change of this ratio is equal to the difference between the urban and rural growth rates, tends to be higher in less urbanized populations and decline as urbanization proceeds. The UN methodology projects changes in the URGD by first using cross-sectional data from 1995 to define a global average relationship between the level of urbanization and the URGD. It then assumes that each country moves from its current URGD to the world norm for its level of urbanization over the next 20 years, and then all countries follow the world norm thereafter.

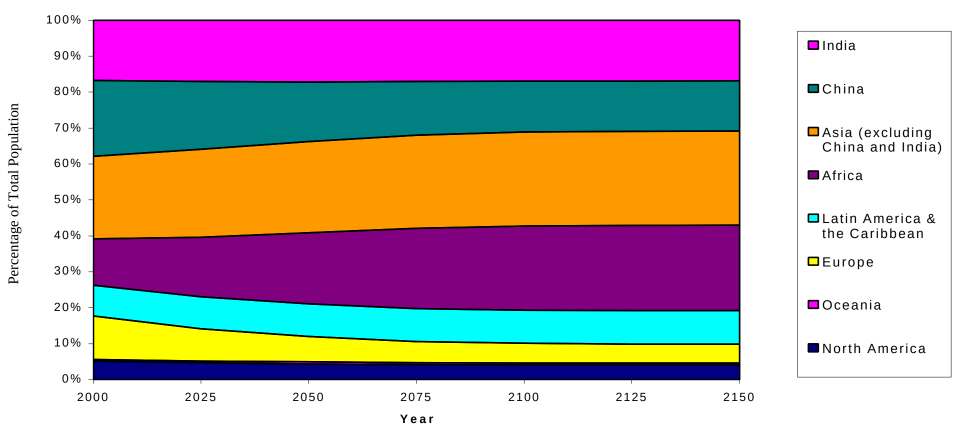
Essentially, the methodology produces an S-shaped projection of the urban proportion of national populations that approaches complete urbanization more and more slowly as time passes. These urban fractions are then applied to the independent projections of total population to produce projections of total urban and rural population.

6.3.2 Regional balance

Figure 12 shows the change in the regional balance of population according to the medium variant of the UN long-range projection. The share of the global population made up by currently industrialized countries (defined as the regions of North America, Oceania, and Europe) declines from about 18% to just over 10%, due mainly to the decline in the share constituted by Europe. The increase in the share made up by currently less developed countries is not distributed equally: Africa's share of the total grows the most over this period from 13% to 24%, while the contribution of China actually falls from 21% to 14%. These conclusions are qualitatively consistent across other scenarios, as well as across institutions.

McNicoll (1999) notes that, to date, population size has not translated neatly into political power in the international system. However, within specific regions, the most populated places tend to wield disproportionate influence. In addition, he argues that demographic "weights" (i.e., relative size) will increase in importance at the global scale, in large part due to claims over natural resources such as the oceans (i.e., fisheries) and atmosphere (i.e., greenhouse gases) if these claims are based at least in part on per capita allocations or access rights.

Figure 12: *Percent of total world population by region, 2000-2150, according to the medium variant of the UN long-range projection.*



6.4 Accuracy of projections

While it is impossible to assess empirically the accuracy of the most recent projections of future population, the record of past projections can shed some light on what reasonable expectations regarding uncertainty might be and might also hold lessons for improving future projections. Yet surprisingly little research has been conducted on this topic. The recent NRC report (NRC 2000), building on earlier work by Keilman (1998), assesses several projections made by the UN and the World Bank since the early 1970s. The report concludes that projections of global population growth made over the past several decades have generally been too high, as measured against the current estimate of the population in the year 2000. These overestimates occurred despite that fact that several earlier projections underestimated the population in the base year of the projection (Keilman 1998, Note 16). These errors were more than compensated for by projections of fertility that turned out to be too high, an outcome driven mainly by the failure to anticipate the speed of the fertility decline in developing countries.

Studies of the accuracy of population projections must wrestle with several choices. First, although accuracy is defined in general as how close projected variables came to estimates of actual values, choices must be made about which variables (e.g., population size, age structure, vital rates) and measures (e.g., absolute error, relative error, point estimates or averages over time) are most appropriate to the task. While global population size is a convenient summary measure, analyses focused on other variables in specific regions can be more informative regarding the causes of errors. In addition, care must be taken to distinguish between inaccuracies resulting from errors in projections of vital rates and those resulting from errors in baseline data. Accuracy studies rely on current estimates of baseline data as representative of "correct" values, but this strategy is problematic itself, since these estimates are constantly being revised. Furthermore, aggregation can complicate analysis since accuracy for a given region may mask offsetting errors at subregional levels. Finally, an important limitation of accuracy studies is the short history of projections (about 50 years) compared to the time horizon of future projections (100-150 years). While a few older long-term projections exist (Lee 1991), differences in methodology make them of questionable relevance to contemporary practice.

Projections from the UN and World Bank have tended to become more accurate over time, as measured by their ability to forecast population in 2000. Projections of the world population made in the early 1970s were in error by 6-7%, while projections made in the 1990s were off by less than 1%; at the country level, average absolute errors declined from about 18% to about 4% over this same period (NRC 2000). Of course most of this decline is due to the fact that more recent projections simply have less time to go wrong before 2000. In addition, baseline data has improved over time. Analyses of errors in country-level projections over equal projection lengths have not yielded clear signs of improvement. For example, projections of population 10 years into the future have not improved substantially over the past several decades (NRC 2000). Whether the ability to forecast trends in fertility, mortality, and migration has improved is also unclear. One difficulty in such exercises is completely controlling for errors in base period data – not only for population size, but for vital rates as well. Baseline errors in all relevant demographic variables are clearly important (Keilman 1990), so it is worth noting that uncertainty in the initial conditions of populations is not explicitly accounted for in global population projections. For example, the UN uses identical base populations for all its scenarios, and IIASA uses identical initial conditions for its probabilistic projections. Thus uncertainty in future global population size is likely larger than their results indicate, and disproportionately so for regions where the baseline population estimates are in question.

Projections of population size tend to tend to be more uncertain under particular circumstances (NRC 2000). They are less accurate (1) in developing countries than in industrialized countries, partly due to limited and less reliable data; (2) in smaller countries than in larger ones, perhaps due to the greater attention devoted to larger countries; (3) in younger and older age groups than in middle age groups, since the effects of incorrect assumptions about fertility and mortality are felt more strongly at these ages; and (4) at the country level than at regional or global levels, since errors at the country level partly cancel each other when aggregated, countries are more susceptible to errors from migration assumptions, and aggregate regions are more influenced by larger countries, for which projections tend to be more accurate.

Projecting vital rates has proved to be difficult. UN projections of death rates have consistently been overly pessimistic, and projections of birth rates have generally been too high, particularly during the 1960s and 70s when developing country fertility fell faster than expected, but also in North America and Europe (Keilman 1998). There are however important exceptions to this general rule. Projections made from 1975 to 1985 of birth and death rates in China were too low, and more recently mortality projections for the former Soviet Union have been too low. In general, fertility has been more difficult to project than mortality when data of equal quality has been available, although the paucity of mortality data makes it a significant source of uncertainty nonetheless.

Figure 13 shows a compilation of projected TFR for the world and several major areas according to the medium variants of past UN projections, as compared to current estimates of actual TFR values over the period 1965-2000. It demonstrates that, averaged over the world (Figure 13a), UN fertility projections have consistently been too high. This has been true in most regions of the world. For example, projections for Latin America (Figure 13b) have suffered from inaccurate base period estimates of fertility, which contributed to overprojecting future fertility. Projections for Europe

(Figure 13c) have benefited from more accurate base period data, but consistently anticipated a halt to the decline in fertility, which in actuality continued to proceed well below replacement level. (Note 17) In a few cases fertility in a major area has been significantly underestimated, but this has tended to occur primarily for base period estimates for older projections, as for example in the 1965 and 1970 projections for China (Figure 13d).

Figure 14 shows a similar compilation for medium variant projections of life expectancy. Averaged over the world (Figure 14a), the UN has generally been overly pessimistic about increases in life expectancy. However the experience with different regions has varied. Projections for Africa (Figure 14b) have consistently been overly optimistic, missing especially the flattening in life expectancy after 1985. In contrast, projections for North America (Figure 14c) have generally been too low (although 1985 and 1990 projections equaled or exceeded estimates), failing to foresee the persistent rise in life expectancy even at already high levels of greater than 70 years. Accurate base period data has been a problem in many instances. Projections for India (Figure 14d) in 1975 and 1980, for example, underestimated then current life expectancies by several years, and even recent estimates of base period life expectancy in Africa (Figure 14b) have turned out to be several years too high.

UN projections of urban population growth in developing countries have also generally been too high (Brockerhoff 2000). The most recent projections, made in 1996, foresee an urban population in 2000 that is 10% smaller than projected in 1980 – just 16 years earlier – using an essentially identical method. This difference is not primarily due to slower than expected growth of population in general, since projections of total population has been revised by only 2% 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 developing 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 (Brockerhoff 2000). The inaccuracy of earlier urban growth projections emphasizes the uncertainty that must be attached to the recent UN projection of urbanization through 2030.

Finally, it must be kept in mind that although analysis of past errors can provide insight into the projection process, demographic change is path dependent; thus 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 over time horizons of a few decades becomes less and less relevant as the horizon of future projections stretches to 100 years or more.

Figure 13a: *Historical projections of Total Fertility Rate (TFR) by the UN over the period 1965 -2000 for (a) the world, (b) Latin America, (c) Europe, and (d) China. The solid blue line shows the most recent estimates of TFR through the 1990-95 period and projected TFR for 1995-2000 from the UN 1998 Revision. Historical projections are labeled according to their base period (i.e., "1965" indicates a projection using 1965-70 as the base period) and specific sources are given in Note 18.*

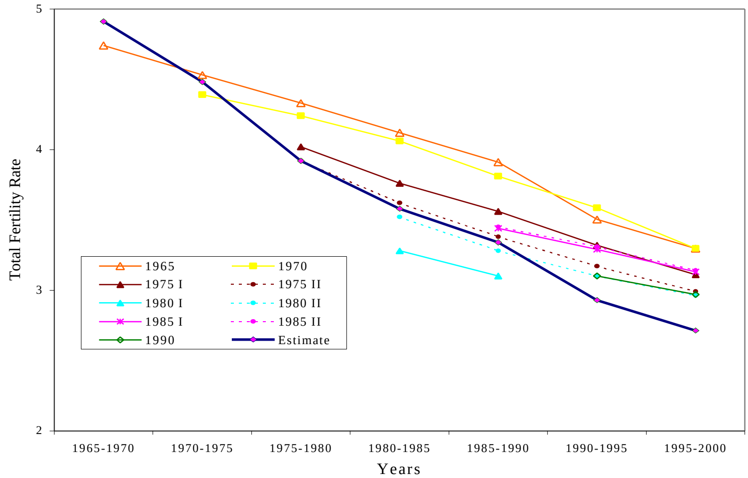


Figure 13b: *Latin America total fertility rate*

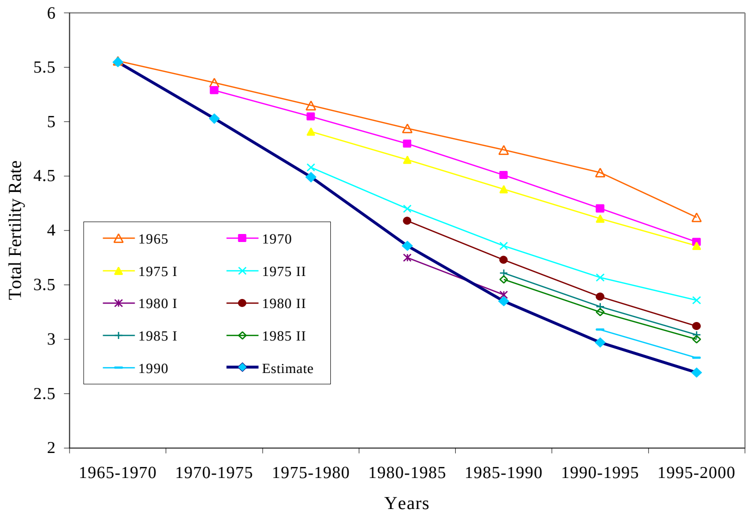


Figure 13c: *Europe total fertility rate*

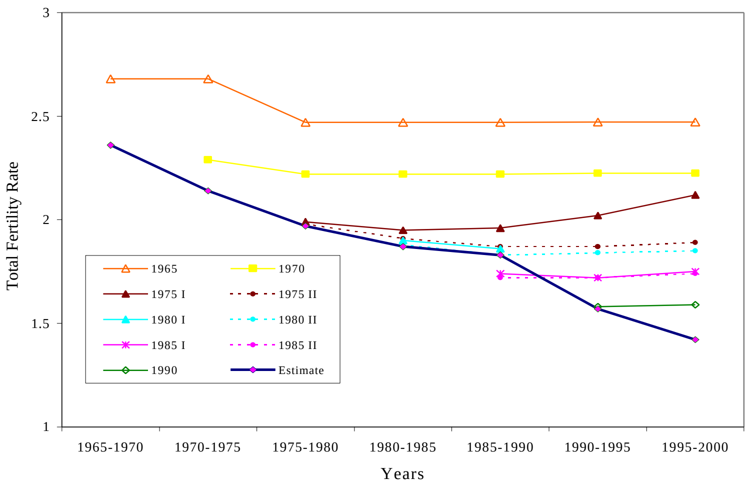


Figure 13d: *China total fertility rate*

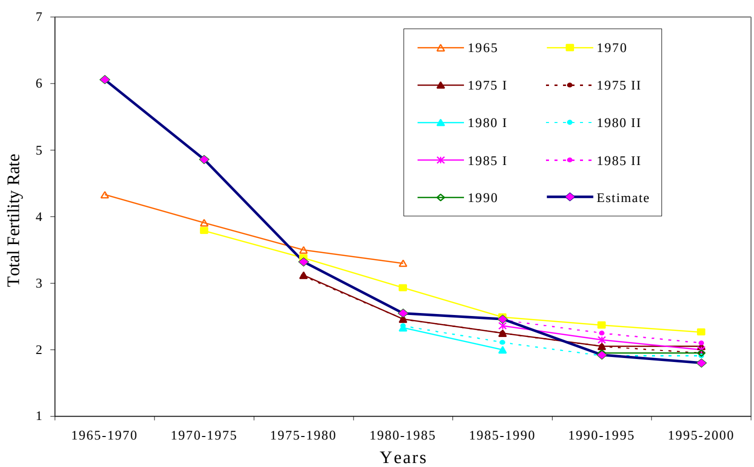


Figure 14a: *Historical projections of life expectancy by the UN over the period 1965-2000 for (a) the world, (b) Africa, (c) North America, and (d) India. The solid blue line shows the most recent estimates of life expectancy through the 1990-95 period and projected life expectancy for 1995-2000 from the UN 1998 Revision. Historical projections are labeled according to their base period (i.e., "1965" indicates a projection using 1965-70 as the base period) and specific sources are given in Note 18.*

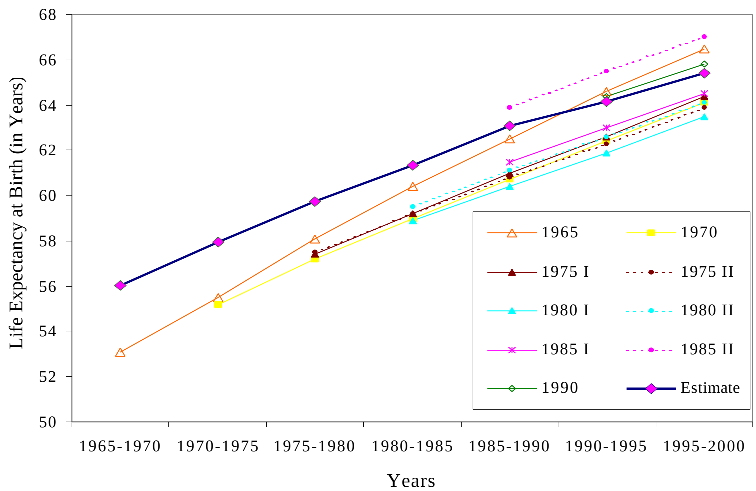


Figure 14b: *Africa life expectancy at birth*

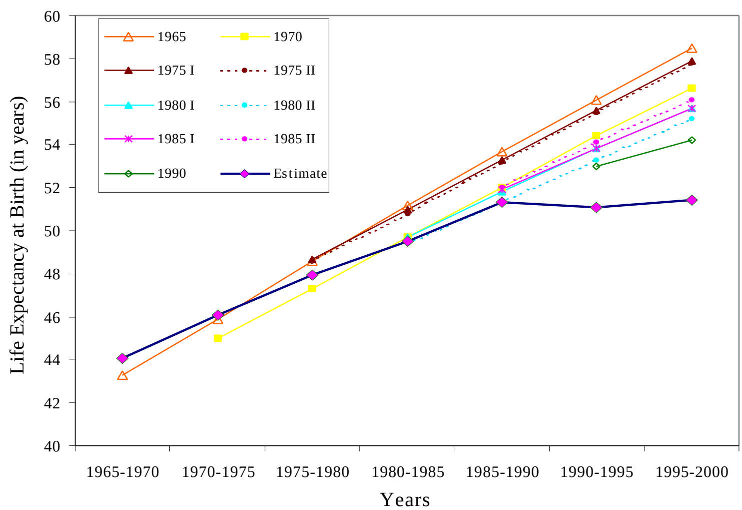


Figure 14c: *North America life expectancy at birth*

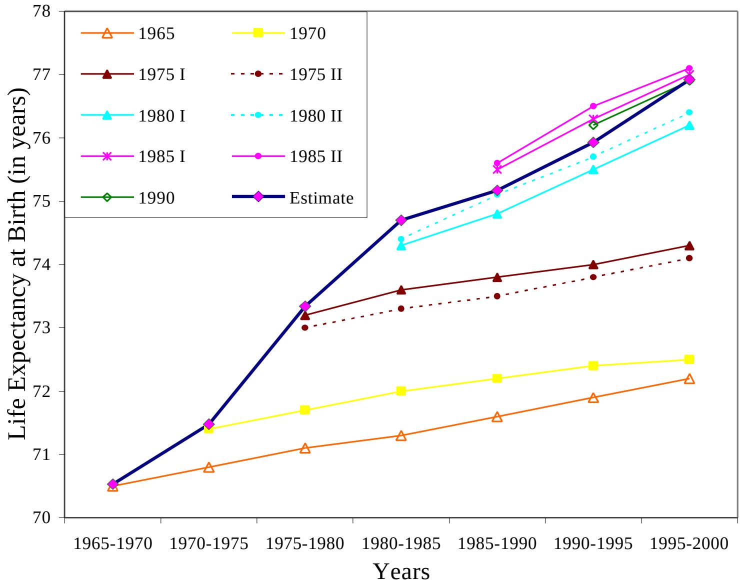
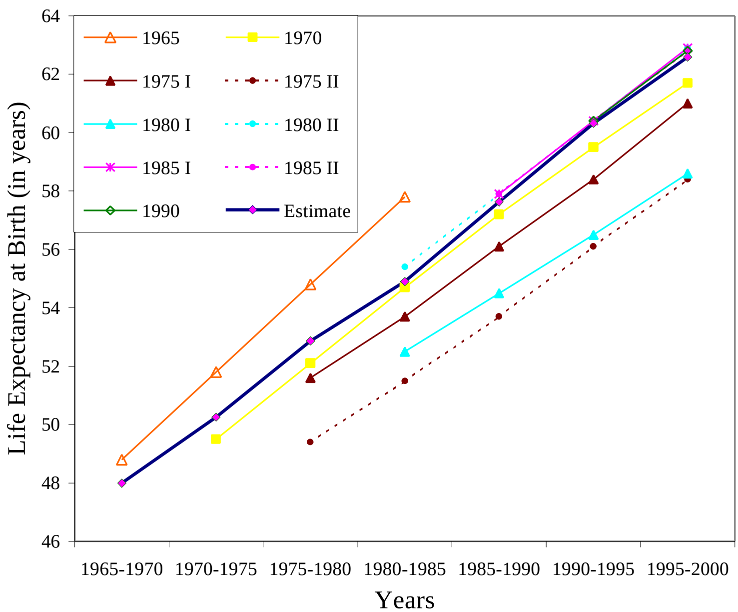


Figure 14d: *India life expectancy at birth*



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Notes

1. Often, the terms "projection" and "forecast" are used interchangeably. However, in some cases demographers differentiate between the terms based on the implied likelihood of the outcome. Projections are defined as the numerical consequences of an assumed set of future paths for fertility, mortality, and migration with no claim as to the likelihood of these consequences actually coming to pass. A forecast, on the other hand, is defined as the most likely projection (IUSSP 1982, Ahlburg and Land 1992), in the same way that a weather forecast describes the most likely outcome. Here, we use the term projection but attach no specific meaning to it. Instead, we specify the interpretations different agencies assign to their outputs.

2. Replacement level fertility is the total fertility rate at which, given prevailing mortality rates and fertility patterns by age group, the childbearing generation would have just enough children to exactly replace itself. If fertility remains constant at the replacement level, population size eventually stabilizes (assuming mortality remains constant and net migration is zero). The Total Fertility Rate corresponding to current mortality conditions is slightly less then 2.1 in developed countries, but is as high as 2.6 in Africa and 2.4 in South Asia where mortality is higher (NRC 2000).

3. For these years, the World Bank’s methodology is included in several paragraphs of table notes (World Bank 1984, pp. 281-282) but they do not indicate the source upon which their information is based nor do they indicate how the various pieces of information related to one another to estimate future rates.

4. Exceptions are the UN, which does not use the cohort-component method for 41 countries or areas whose populations were below 150,000 in 1995, and the US Census Bureau, which uses an alternative method for 14 small countries or territories with a combined total 1998 population of about 800,000 people. These exceptions make up only a small fraction of the global population.

5. An exception is the US Census Bureau, which uses single year time steps and age groups.

6. However, it is possible to project total population using an aggregate method, and to calculate a consistent age structure after the fact (Lee et al 1995).

7. The same cannot be done with the UN scenarios because net migration would not be balanced for the world.

8. Although family planning programs have been the main intervention to lower fertility, these programs have often been implemented concomitantly with general economic development programs, educational programs, and health programs, each of which may have an indirect effect on changing fertility.

9. Exceptions are those countries for which data on the completed fertility of the cohort born in 1962 is available. In these cases, the average of the 1962 cohort fertility and the target level as described in the text is used.

10. If fertility in the base period was lower than the ultimate level as determined by subtracting 0.4 from the ultimate fertility level in the medium variant, the fertility in the base period was used as the ultimate level.

11. The high assumptions are 2.3 in North America and Eastern Europe, and 2.1 in Western Europe and Japan/Australia. The assumptions are slightly higher for North America because of its different ethnic composition.

12. Brazil and Thailand were included not because they had met the seroprevalence cut-off, but rather because the country-specific modeling work had already been completed (USCB 1999) and presumably indicated that adjustments for AIDS mortality were warranted.

13. For Nigeria, the UN assumes 3.4% adult HIV prevalence in 1997 (using the age distribution for 1995 from the UN 1998 Revision this translates to total country prevalence of 1.9%), and projects a peak in adult prevalence in about 2010 of 10% (=6.0% total country prevalence; UN 1999d). USCB assumes 2.2% total country prevalence in 1995, climbing to a peak of 15% in 2010 (USCB 1999) – two and a half times the level projected by the UN. For Brazil, the USCB estimates total country prevalence in 1995 at 0.7%, whereas the UN assumptions are lower; 0.5%

adult HIV prevalence in 1997, and projecting a peak of just over 1.2% in 2005 (=0.9% total country prevalence). The two institutions model the spread of HIV and the development of AIDS using different tools. The USCB uses the iwgAIDS model developed under sponsorship of the US State Dept (Stanley et al 1991). The UN uses EPIMODEL, developed by the WHO (Chin and Lwanga 1991). The USCB refers to "country specific modeling" that was done for Brazil (and Thailand). The description of this modeling implies that the iwgAIDS model was used in Brazil as in other countries, although the substantial homosexual and IV drug-user component of the epidemic was unique relative to African nations.

14. According to the UNHCR, there were about 13 million refugees in 1995, and an additional 13 million "persons of concern to the UNHCR," a group which includes people forced from their homes or communities but still residing in their own countries. Since Myers includes displaced persons who have not crossed international borders in his definition of "environmental refugees", the total figure – 26 million – is the most relevant for comparison.

15. The UN revised their earlier urbanization projections in 1999, based on the 1998 *Revisions.*

16. Errors in baseline data were especially important for elderly age groups before 1980. Since then errors in baseline population size data have been <1% at all ages (Keilman 1998).

17. The figure for Europe has not been corrected for changing regional definition over time; results are therefore preliminary.

18. Notes to Figures 13 and 14:

    The following sources were used for each projection. This list is identical to the one used by Keilman (1998), with the exception of the 1994 Revision. Note that neither projections of TFR nor life expectancy could be extended through 1995-2000 for China, India, and the United States in the 1965 projection.

Projection*	**UN Publication**
1965	(1973) World Population Prospects as Assessed in 1968. Population Studies, No. 53
1970	(1977) World Population Prospects as Assessed in 1973. Population Studies, No. 60
1975 I	(1980) Selected Demographic Indicators by Country, 1950-2000: Demographic estimates and projections as assessed in 1978
1975 II	(1981) World Population Prospects as Assessed in 1980. Population Studies, No. 78

1980 I	(1985) World Population Prospects: Estimates and Projections as Assessed in 1982. Population Studies, No. 86
1980 II	(1986) World Population Prospects: Estimates and Projections as Assessed in 1984. Population Studies, No. 98
1985I	(1989b) World Population Prospects: 1988. Population Studies, No. 106
1985 II	(1991b) World Population Prospects, 1990. Population Studies, No. 120
1990	(1995) World Population Prospects: The 1994 Revision, No. 145
Estimate	(1999) World Population Prospects: The 1998 Revision, Volume I, Comprehensive Tables.

* Projections are labelled according to the last year for which population was estimated rather than projected.

For three of the projections, the United Nations publishes data for gross reproduction rate (GRR)* instead of TFR. In these instances, GRR was converted to TFR by multiplying the GRR by sex-ratio at birth °. TFR was calculated as follows:

Projection	TFR calculations
1965	GRR * 1.06
1970	GRR * 1.06
1980I	GRR * 1.05

For four of the projections, the United Nations publishes data for sub-regions of Asia instead of Asia as a whole. Data for as Asia was therefore aggregated as follows:

Projection	Asia Aggregation
1965	(East Asia + South Asia)/2
1970	(East Asia + South Asia)/2
1975I	(East Asia + South Asia)/2
1975II	(East Asia + South Asia)/2

* Gross Reproduction Rate: Average number of daughters born per woman in a group of women passing through the reproductive span if mortality were zero and they experienced the given age-specific fertility rates at each age

° Sex Ratio at Birth: the number of males per 100 females; normally around 105

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