Economic & Social Affairs

World Population Prospects
The 2012 Revision

Methodology of the United Nations Population Estimates and Projections

United Nations
New York, 2014

ESA/P/WP.235

Department of Economic and Social Affairs
Population Division

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DESA

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Note

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PREFACE

This report provides a detailed overview of the methodology used to produce the *2012 Revision* of the official United Nations population estimates and projections, prepared by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. The *2012 Revision* is the twenty-third round of global population estimates and projections produced by the Population Division since 1951.

The report first describes the way that country estimates have been prepared and then explains the approaches and assumptions that were used to project fertility, mortality and international migration up to the year 2100. The report also provides an overview of the variants used in generating the different sets of population projections as well as information on the recently developed probabilistic projection methods. The Population Division has continued to develop the methodology for producing probabilistic projections for all countries and areas of the world, which began in the *2010 Revision* with the projections of fertility. In addition to updating the methods used to produce the future trajectories of fertility, the *2012 Revision* incorporates, for the first time, probabilistic projections of mortality. It should be stressed, however, that making projections to such a far time horizon at the country level is subject to a high degree of uncertainty. In that regard, users are invited to focus not only on the outcomes of the medium variant, which corresponds to the median of several thousand projected country trajectories for each component, but also to appreciate the meaning of the uncertainty bounds in such an exercise. Detailed information on the uncertainty bounds for different components at the country level can be accessed on the Population Division's website at *www.unpopulation.org*. The standard outputs of the *2012 Revision* do not include the probabilistic population projections and are restricted to a set of projection variants that correspond to those included in prior revisions of *World Population Prospects*.

For further information about the *2012 Revision*, please contact the Director, Population Division, United Nations, New York, NY 10017, USA (Fax: 1 212 963 2147; e-mail: population@un.org).

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EXPLANATORY NOTES

The following symbols have been used in the tables throughout this report:

Two dots (..) indicate that data are not available or are not reported separately.
A hyphen (-) indicates that the item is not applicable.
A minus sign (-) before a figure indicates a decrease.
A full stop (.) is used to indicate decimals.
Years given refer to 1 July.
Use of a hyphen (-) between years, for example, 1995-2000, signifies the full period involved, from 1 July of the first year to 30 June of the second year.

Numbers and percentages in tables do not necessarily add to totals because of rounding.

References to countries, territories and areas:

The designations employed and the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

The designation “more developed” and “less developed” regions are intended for statistical purposes and do not express a judgment about the stage reached by a particular country or area in the development process. The term “country” as used in this publication also refers, as appropriate, to territories or areas.

More developed regions comprise all regions of Europe plus Northern America, Australia/New Zealand and Japan. Less developed regions comprise all regions of Africa, Asia (excluding Japan), and Latin America and the Caribbean as well as Melanesia, Micronesia and Polynesia. Countries or areas in the more developed regions are designated as “developed countries”. Countries or areas in the less developed regions are designated as “developing countries”.

The least developed countries, as defined by the United Nations General Assembly in its resolutions (59/209, 59/210, 60/33, 62/97, 64/L.55, 67/L.43) included 49 countries in June 2013: 34 in Africa, 9 in Asia, 5 in Oceania and one in Latin America and the Caribbean. Those 49 countries are: Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, São Tomé and Príncipe, Senegal, Sierra Leone, Solomon Islands, Somalia, South Sudan, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Republic of Tanzania, Vanuatu, Yemen and Zambia. These countries are also included in the less developed regions.

The group denominated “other less developed countries” comprises all countries in the less developed regions minus the least developed countries.

The term “sub-Saharan Africa” is used to designate the countries in Africa that exclude those in Northern Africa.

Countries and areas are grouped geographically into six major areas designated as: Africa; Asia; Europe; Latin America and the Caribbean; Northern America, and Oceania. These major areas are further divided into 21 geographical regions.

The names and composition of geographical areas follow those presented in “Standard country or area codes for statistical use” (ST/ESA/STAT/SER.M/49/Rev.3), available at http://unstats.un.org/unsd/methods/m49/m49.htm.

The following abbreviations have been used:

AIDS	Acquired immunodeficiency syndrome
AR1	Autoregressive model
BHM	Bayesian Hierarchical Model
CSSS	Center for Statistics and the Social Sciences
DESA	Department of Economic and Social Affairs
DHS	Demographic and Health Surveys
GHS	General Household Survey
HIV	Human immunodeficiency virus
IGME	Inter-agency Group for Child Mortality Estimation
LDCs	Least developed countries
MICS	Multiple Indicator Cluster Survey
MIS	Malaria Indicator Survey
MDGs	Millennium Development Goals
SAR	Special Administrative Region
TFR	Total fertility rate
UNAIDS	Joint United Nations Programme on HIV/AIDS
WFS	World Fertility Survey
WHO	World Health Organization

INTRODUCTION

The preparation of each new *Revision* of the official population estimates and projections of the United Nations involves two distinct processes: (a) the incorporation of new information about the demography of each country or area of the world, involving, in some cases, a reassessment of the past; and (b) the formulation of detailed assumptions about the future paths of fertility, mortality and international migration, again for every country or area of the world.

The population estimates and projections contained in this *Revision* cover a 150 year time horizon, which can be subdivided into past estimates (1950-2010) and future projections (2010-2100). Past estimates of demographic variables were taken either directly from national statistical sources, or estimated by staff within the Population Division on the basis of the best available national or international estimates at the time. In some cases, it was deemed necessary to adjust the original data for deficiencies in age misreporting, under-enumeration, or underreporting of vital events. Adjustments were also made to take account of international migration flows. The year 2010, separating the past estimates from the projections, is called the base year of the projections. The projection period of this *Revision* covers 90 years and ends in 2100.

Population projections prepared by the United Nations Population Division have been produced for a number of different variants to highlight, for instance, the effect of changes in the assumptions about the future trajectories of fertility on the future size and structure of the population. More recently a probabilistic approach has been added to project certain components such as total fertility and life expectancy at birth by sex. Population estimates and projections were carried out for a total of 233 countries or areas. Detailed results have been published for 201 countries or areas with 90,000 inhabitants or more in 2013; for the remaining 32 that fell below that threshold, only total population and growth rates have been made available.

In order to ensure the consistency and comparability of population and demographic estimates within and across countries, certain steps were undertaken. New demographic information was evaluated partly by analysing the impact of its incorporation on recent changes in population dynamics and by comparing the simulated outcome with existing estimates of the age and sex structure of the populations closest to the base year. Different methods were also applied to carry out other evaluations. With respect to the projection period, general guidelines or specific applications were used to determine the paths that fertility, mortality and international migration are expected to follow in the future. In some cases, deviations from the general guidelines or the default trajectories implied by the applications were required. This was mainly the case for the projection of net international migration and life expectancy at birth for selected countries and for some countries where the prevalence of HIV/AIDS is high.

This report first describes the way that the estimates were revised during the preparation of the *2012 Revision*. It then examines the approaches and assumptions that were used to project fertility, mortality and international migration up to the year 2100. The report also contains an overview of the variants used in generating the different sets of population projections as well as information on the probabilistic projection methods.

I. THE PREPARATION OF POPULATION ESTIMATES

A. GENERAL ANALYTICAL STRATEGY USED TO PRODUCE PAST DEMOGRAPHIC ESTIMATES

With each revision of World Population Prospects (WPP) the United Nations Population Division carries out a re-estimation of historical demographic trends for countries and territories of the world (Heilig et al., 2009). These population estimates are based on the most recently available data sources, such as censuses, demographic surveys, data from vital and population registers and various other sources. With each new data collection the time series of fertility, mortality and migration, as well as population trends by age and sex, can be extended and, if necessary, retrospectively corrected. For countries with highly deficient demographic data, or many years without a census or demographic survey, the availability of new data can often lead to a reassessment of historical demographic trends.

For most countries in the more developed regions, the availability of detailed information on fertility and mortality trends over time and of periodic censuses of the population has greatly facilitated the task of producing reliable estimates of past population dynamics. Yet, even for these countries, the data on international migration flows was sometimes deemed inadequate. In that regard, consistency between population counts and the components of population change was sometimes achieved by assigning to net international migration the residual population estimate obtained by comparing the actual intercensal population growth rate with independent estimates of natural increase based on fertility and mortality estimates. Within this exercise, adjustments in population counts were sometimes considered or assumed.

For many countries in the less developed regions, the estimation of past trends is usually more complex. In these countries, demographic information may be limited or lacking and the available data can be unreliable. In numerous cases, therefore, consistency can only be achieved by making use of models in conjunction with methods of indirect estimation (Moultrie et al., 2013; United Nations, 1983, 2002). In extreme cases, when countries had no data referring to the past decade or two, estimates were derived by inferring levels and trends from those experienced by countries in the same region that have a socio-economic profile similar to the country in question. However, since the 1970s the emphasis put on surveys and census-taking in the developing countries has considerably improved the availability of demographic information.

The data sources used and the methods applied in revising past estimates of demographic indicators (i.e., those referring to 1950-2010) are available online[1] and in an Excel file (WPP2012_F02_METAINFO.XLS).

At the global level, data from censuses or official estimates based on censuses, population registers and surveys referring to 2005 or later were available for 197 countries or areas, 85 per cent of the 233 countries or areas for which projections are carried out. For 28 countries, data were available from the 1995-2004 global censuses round, and for the remaining 8 countries data availability ranged from the year 1994 in Equatorial Guinea to 1970 in Angola.

Aside from relying on census information concerning the distribution of the population by age and sex, in order to estimate the population as of 1 July 2010, the base year, trends in fertility, mortality and international migration up to this date must be established. Ideally, complete time series of annual age-specific fertility rates, life tables and age-specific net international migration rates by sex are needed. In practice, the amount of information available is usually less comprehensive, consisting often of no more than the average age-specific fertility rates experienced by women over a few periods of various lengths,

[1] Data sources and related meta-information for the *2012 Revision* of the *World Population Prospects* are available for each country from the following web page: http://esa.un.org/unpd/wpp/Documentation/data-sources.htm.

estimates of infant or child mortality at several points in time and, less commonly, one or two life tables for different periods. For developing countries, estimates of recent fertility and child mortality are often derived from surveys, especially when countries lack a civil registration system or have one that does not have sufficient coverage of all vital events. For countries with a reliable civil registration system, as is the case in most developed countries and in some developing countries, data on both fertility and mortality by age and sex are theoretically available on a continuous basis. However, owing to either delays in processing the data or the difficulty of estimating appropriate denominators to calculate age-specific fertility or mortality rates, fertility schedules and life tables may only be available for selected years. In preparing the revised estimates of the base-year population, such information had to be taken into account together with trends in other indicators, such as changes in the overall number of births. Depending on the availability of recent information in a given country, "estimates" for the period 2005-2010 or the year 2010 are in some cases based on a "projection". Lastly, in some cases, information referring to the years 2011 or 2012 was also used to inform the 2010-2015 projected values.

B. Major analytical steps used to estimate past population by age and sex, fertility, mortality, and migration between 1950 and 2010

One of the major tasks in revising the estimates and projections of each country of the world is to obtain and evaluate the most recent information available on each of the three major components of population change: fertility, mortality and international migration. In addition, newly available census information or other data providing information on the age distribution of the population should also be evaluated. However, this process of updating and revising population estimates typically entails not only the separate evaluation of the quality of the different estimates available, but also - and more importantly - the search for consistency among them. The key task is therefore to ensure that for each country past trends of fertility, mortality and international migration are consistent with changes in the size of the population and its distribution by age and sex.

For most countries in the more developed regions, the availability of the detailed information on fertility and mortality trends over time and of periodic population censuses greatly facilitates the task of producing reliable estimates of past population dynamics. For many countries in less developed regions, however, the estimation of past population trends requires a complex procedure.

Following the UN Principles and Recommendations on Censuses (United Nations, 2008), most countries conduct a census about once per decade. Altogether more than 1,600 censuses have been conducted worldwide since the 1950s, providing potentially a wealth of data for analysis and monitoring. When countries have conducted several censuses, the results can be analysed not only for each census independently but also altogether by following cohorts as they age through time and appear in successive censuses (Gerland, 2013; Heilig et al., 2009; Spoorenberg and Schwekendiek, 2012).

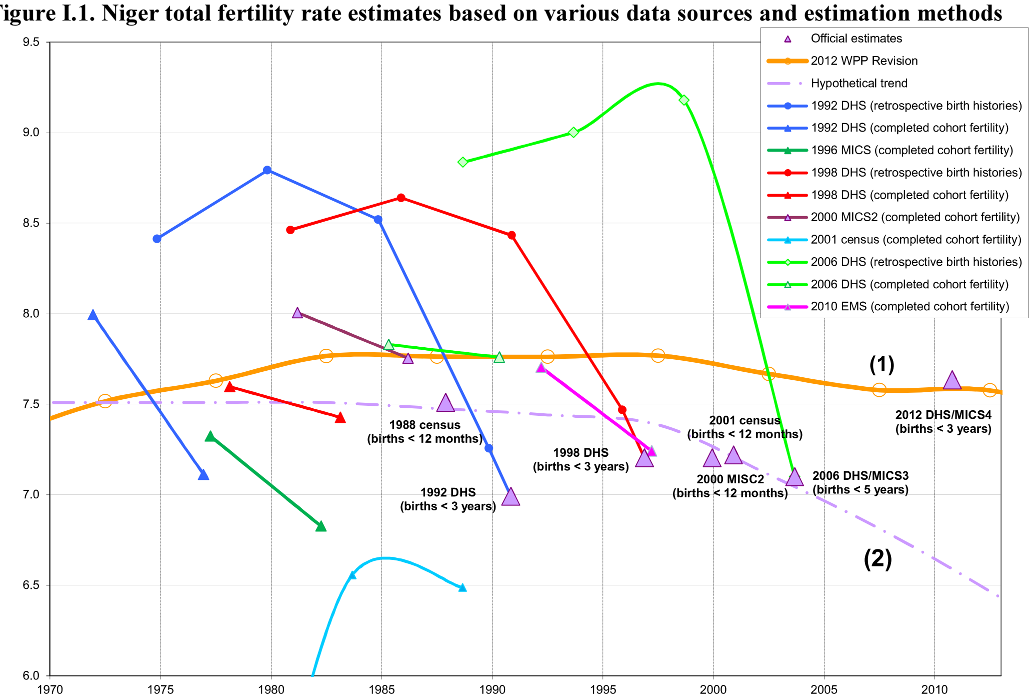
The overall analytical approach used in the *2012 Revision* consisted of four major steps:

1. *Data collection and estimation*: Analysts collect available data from censuses, surveys, vital and population registers, analytical reports and other sources for a given country[2]. These data are reviewed and used to estimate populations, fertility, mortality and net international migration components. However, for many countries of the less developed regions, empirical demographic information may be limited or lacking and the available data can be unreliable. In these cases, models and indirect measures of fertility and mortality estimation have also been used to derive

[2] Traditionally, the data are provided by the UN Statistics Division (Demographic Yearbook), Regional Commissions (e.g., ECLAC), other UN agencies (e.g., WHO, UNICEF, UNAIDS) and by international databases (e.g., Human Mortality Database, Human Fertility Database), as well as microdata archives (e.g., DHS, MICS, IPUMS-International). Ideally, each new dataset for a country would include a census population by single or abridged age groups and sex, a recent life table, age-specific fertility rates, and net-migration by age and sex.

estimates. Typically, analysts assemble a collection of estimates from various sources for each component (e.g., see figure I.1 for total fertility estimates of Niger). In many cases, estimates derived from different sources or based on different modelling techniques can vary significantly, and all available empirical data sources and estimation methods should be compared. Various techniques have been used to identify the most likely time-series of fertility, mortality and international migration data.

Figure I.1. Niger total fertility rate estimates based on various data sources and estimation methods

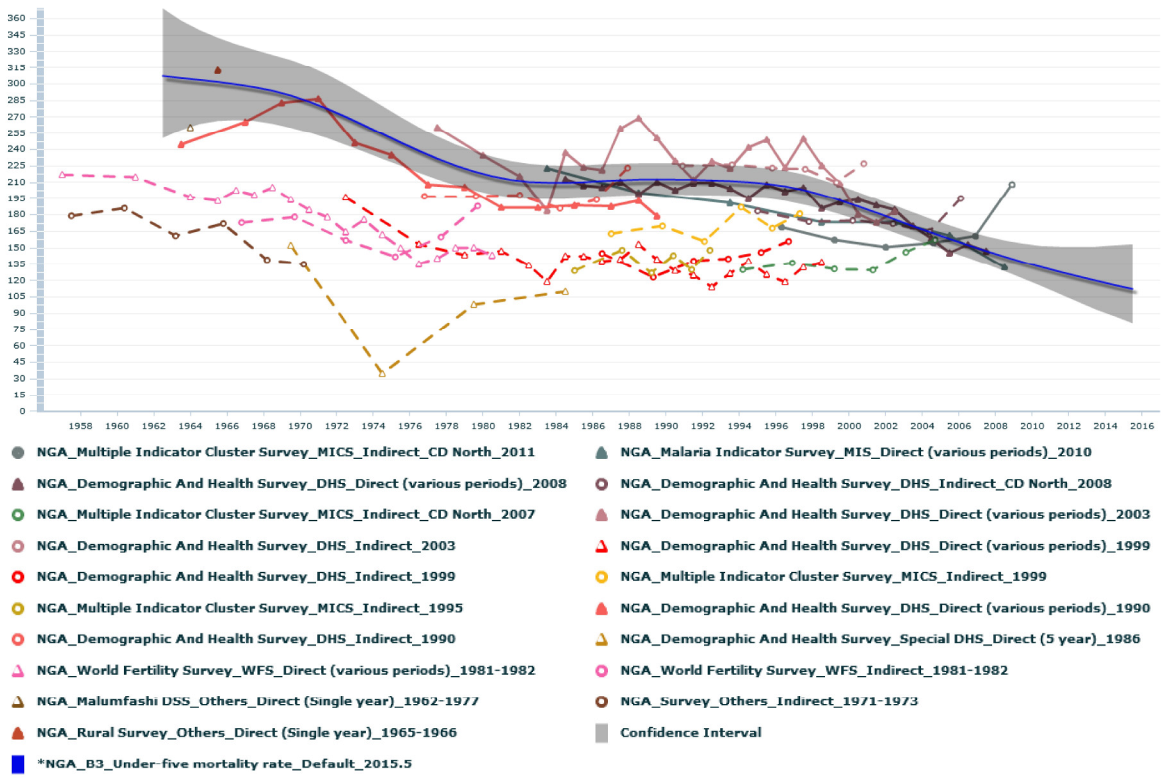


This figure illustrates the "cloud" of empirical data points of total fertility rates derived from different data sources in Niger. The thick solid line (marked 1) represents the 2012 Revision TFR estimates between 1970 and 2012. The lower dashed line (marked 2) corresponds to the uncorrected estimates of total fertility in Niger, based on the 1988 and 2001 censuses as well as the values for several DHS that were available at the time.

Intercensal demographic trends were reconstructed for each component of demographic change. This has required the consolidation of empirical evidence ideally back to 1950 or even earlier. In many instances, some of this information was missing or only available through retrospective sources. In addition, different data sources as well as different analytical methods can produce substantially different estimates of underlying rates, and frequent non-sampling errors can bias series in systematic ways. To address these various challenges, trends by age and sex (or overall summary indices like ${}_5q_0$ and ${}_{45}q_{15}$ when time series of age-specific mortality rate were unavailable) were generated either through expert-based opinion reviewing and weighting each observation analytically, or, in more recent years, using automated statistical methods (for example, pooled analysis using Loess (local regression) or cubic splines with analytical weights (Obermeyer et al., 2010; Rajaratnam et al., 2010; Wang et al., 2012), or by using a bias-adjusted data model to control for systematic biases between different types of data (Alkema and New, 2013; Alkema et al., 2012).

The overall analytical approach used to measure under-five mortality followed that of the United Nations Inter-agency Group for Child Mortality Estimation (IGME) (Hill et al., 2012), which fitted a robust trend through the various data sources. Further details about the methodology for estimating child mortality and detailed set of series included in the analysis are publicly available for all countries at http://www.childmortality.org. As an example, figure I.2 provides an overview of the underlying empirical estimates for Nigeria, which were used to derive child mortality ($_5q_0$) estimates for both sexes combined. Note that the various series represented by dashed lines were excluded from the analysis due to their lack of reliability or national representativity.

Figure I.2. Nigeria $_5q_0$ based on various data sources and estimation methods with IGME fitted trend



To estimate sex-specific under-five mortality, the analysis and modelling of time trends used the sex ratio of mortality for $_1q_0$ and $_5q_0$ (Sawyer, 2012) due to the smaller number of observations available for sex-disaggregated mortality. Mortality sex differentials were applied to the mortality for both sexes combined to obtain $_1q_0$ and $_5q_0$ by sex, with $_4q_1$ derived as a residual[3].

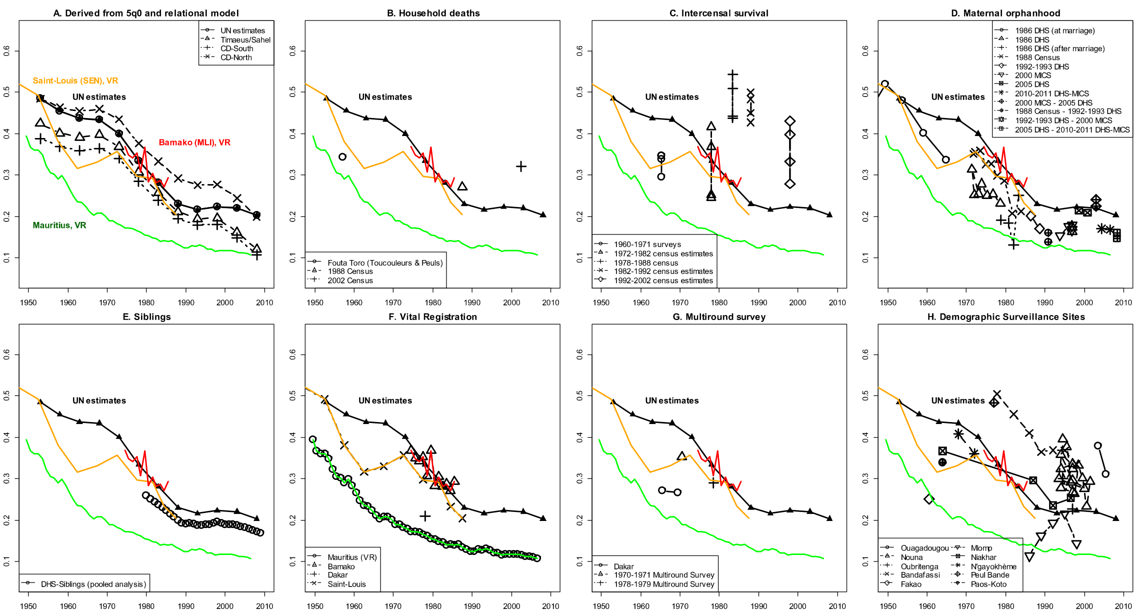
For adult ages, age and sex-specific mortality rates (or summary indices of adult mortality such as $_{35}q_{15}$ or $_{45}q_{15}$) were analysed using a variety of data sources and estimation methods based on data availability and reliability (Hill, Choi and Timaeus, 2005; Masquelier, 2012; Moultrie et al., 2013; Obermeyer et al., 2010; Rogers and Crimmins, 2011; United Nations, 1983, 2002).

In countries lacking nationally representative vital registration, adult mortality estimates can be derived from various data sources using a variety of estimation methods (see, for example, Figure I.3 for various estimates of female adult mortality in Senegal). If all estimation methods and data sources were internally consistent, all figures should agree but as seen through the following set of plots, the reality is quite complex and estimates are often biased. Figure I.3 presents by estimation method the different female $_{45}q_{15}$ estimates derived from various data sources. Each set

[3] Child mortality is computed as $_4q_1 = 1 - \frac{l_5}{l_1} = 1 - \frac{(1 - {}_5q_0)}{(1 - {}_1q_0)}$.

of empirical estimates are compared to three reference series: UN estimates (*World Population Prospects: the 2012 Revision*), urban vital registration for Saint Louis (Senegal), Bamako (Mali) and Ouagadougou (Burkina Faso) and Mauritius vital registration. These various sets of estimates can be roughly categorized into four types: (a) model-based, (b) direct estimates (e.g., household deaths, survival from sibling histories), (c) indirect estimates (e.g., paternal and maternal orphanhood methods) and (d) small areas.

Figure I.3. Senegal female adult mortality estimates based on various data sources and estimation methods



As seen in Figure I.3, UN estimates of female adult mortality (${}_{45}q_{15}$) for Senegal conform to the implied relationship between child mortality and adult mortality based on the North model of the Coale-Demeny Model Life Tables in the 1950s, and are assumed to converge over time towards the South model of the Coale-Demeny Model Life Tables by the 1990s (Panel A). In addition, recent household deaths data from the 1988 and 2002 censuses (Panel B) and 1978-1979 Multiround Survey (Panel G) were also considered together with parental orphanhood from these censuses and surveys (Panel D), and estimates derived from DHS siblings survival (Panel E). Intercensal survivorship from successive census age distributions (smoothed and unsmoothed) for periods 1976-1988 and 1988-2002 (Panel C) was reviewed, but excluded from the analysis due to lack of reliability. Data from urban vital registration (Panel F) and West African rural demographic surveillance sites (Panel H) were also considered as baseline.

2. *Evaluation and adjustments:* In a second step the data were evaluated for geographical completeness and demographic plausibility. Post-enumeration surveys were used if available to evaluate the quality of census data. If necessary, adjusted data were obtained or adjustments were applied using standard demographic techniques, such as for under-enumeration of young children or age-heaping using smoothing.

   For countries with deficient vital statistics, adult death registration data were typically evaluated (and adjusted if necessary) using death distribution methods[4] for various combinations of age groups, and with smoothed or unsmoothed census age distributions. When available, the relationship between ${}_{5}q_{0}$ and ${}_{45}q_{15}$ (or other similar summary indices) by sex was used for the purposes of additional validation against reference mortality datasets such as the Human Mortality Database (Gerland, 2013).

[4] Generalized Growth Balance (GGB), the Synthetic Extinct Generations (SEG i.e., Bennett-Horiuchi unadjusted and adjusted for census coverage change) and a hybrid of the two approaches (GGB/SEG).

Mortality rates at older ages (e.g., 85 and over) often required additional smoothing or adjustment using the Kannisto model of old-age mortality (Thatcher, Kannisto, and Vaupel, 1998) fitted on data from age 75 onward. Old age mortality rates were adjusted[5] if necessary to insure consistency by (a) age (monotonic increase), (b) sex over time (monotonic decline) and (c) between sex by period (male greater or equal to female).

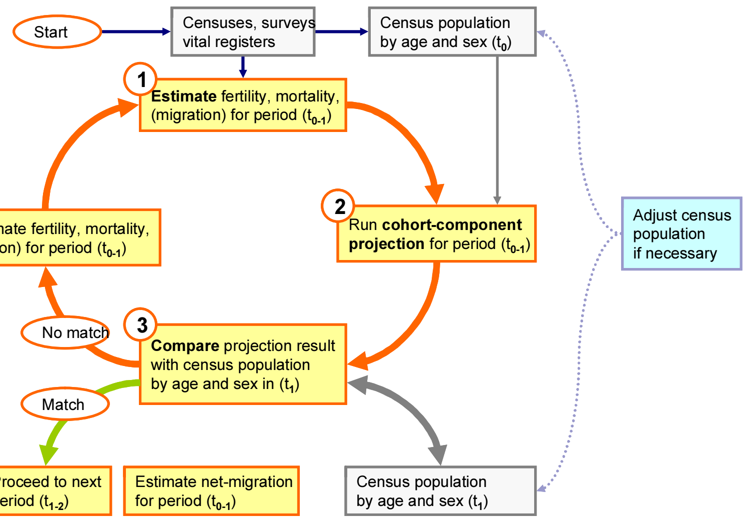
For countries where no, or only minimal, demographic information was available, demographic models were used to estimate fertility, mortality and migration. Estimates contained in previous *World Population Prospects* were carefully reviewed and, if necessary, were revised based on the new data.

3. *Consistency checking and cross-validation*: The previous steps provided initial sets of independent estimates for each demographic component (population, fertility, mortality, and migrations). However, the methods used focus on only one demographic component (such as fertility or mortality) without taking into account the interaction with the other demographic components. This can be avoided if the separate estimates for fertility, mortality and migration are integrated into a cohort-component projection framework where these demographic rates are simultaneously applied to a base population in order to compute subsequent populations by age and sex. Typically, population "projection" uses vital rates and migration to project a set of age-specific population counts in the baseline year, denoted t_0, forward in time. In its simplest form, the population in year t+n, $t_0 \leq t \leq t+n$, equals the population in year t plus the intervening births and net migration, minus the intervening deaths (Preston, Heuveline and Guillot, 2001; Whelpton, 1936). This is known as the demographic balancing relationship.

   The estimates obtained from steps 1 and 2 were subjected to a series of checks whereby the relationship between the enumerated populations and their estimated intercensal demographic components (fertility, mortality, migration) were tested for internal consistency. For countries where several recent censuses are available, intercensal consistency was analysed by projecting the population between census years – using the initial estimates for fertility, mortality and migration obtained in steps 1 and 2. If the population by age and sex of the subsequent censuses could not be matched by the projection, adjustments for one or more demographic components were made (figure I.4) – and in some cases the initial starting population itself was revised appropriately after back-surviving cohorts from one or multiple censuses with more plausible results. Projection consistency was achieved through an iterative step-by-step "project-and-adjust" process from one census to the next, and considered altogether to insure optimal overall intercensal cohort consistency.

[5] Especially for earlier periods with more deficient old age mortality data (e.g., 1950-1980 in some countries), mortality rates at age 75 and over were adjusted using the average rate of mortality increase by age based on the historical experience of the Human Mortality Database (University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org for countries at similar levels of mortality.

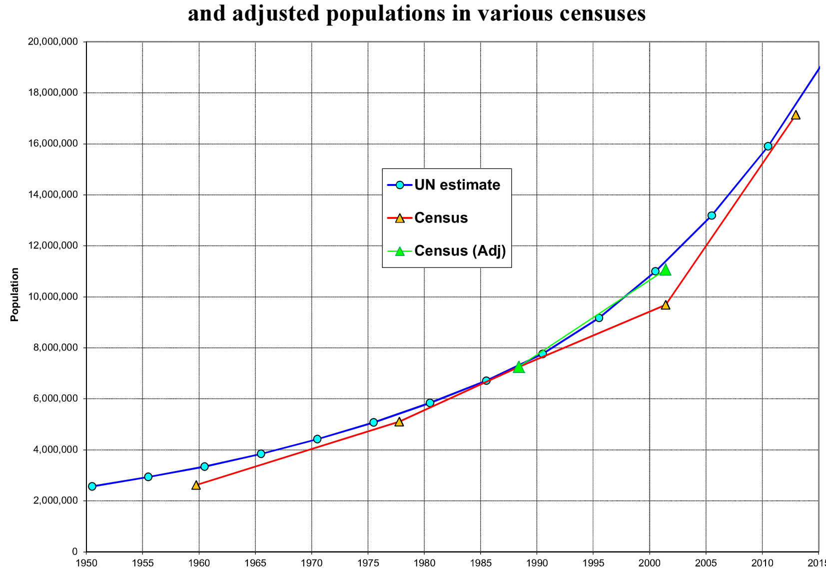
Figure I.4. Process used to insure intercensal consistency between demographic components and populations



The diagram above illustrates how individual estimates of fertility, mortality and net-migration are "tested" for internal consistency within a cohort-component projection framework for the period between t_0 and t_1. This procedure is applied in every new revision of the World Population Prospects. Past estimates are re-evaluated when new information becomes available; therefore, with every revision past demographic trends may be adjusted.

The validation with enumerated census populations can be conducted on the overall total as seen in figure I.5 for Niger plotting the total population by year as enumerated in each census (red line with yellow triangles), adjusted for net-omissions by age and sex using post-enumeration surveys (green line with triangles), and based on the UN estimated reconstruction using an initial 1950 base population and subsequent trends in fertility, mortality and international migration.

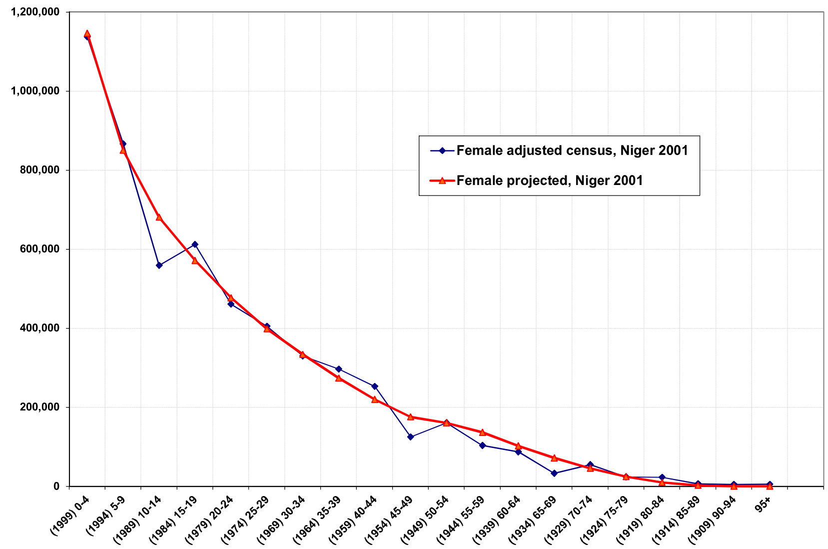
Figure I.5. Niger total population: comparison of UN estimate and the enumerated and adjusted populations in various censuses



The UN estimates for Niger are consistent with the 1959 sample survey and the 1977, 1988 and 2001 censuses (adjusted for under-enumeration), as well as with provisional totals from the 2012 census, and with estimates of the implied trends in fertility, mortality and international migration. The differences between UN estimates and the different adjusted censuses are modest (< 3 per cent), and most of these differences can be explained by misreporting and underreporting in some age groups as seen in figure I.6.

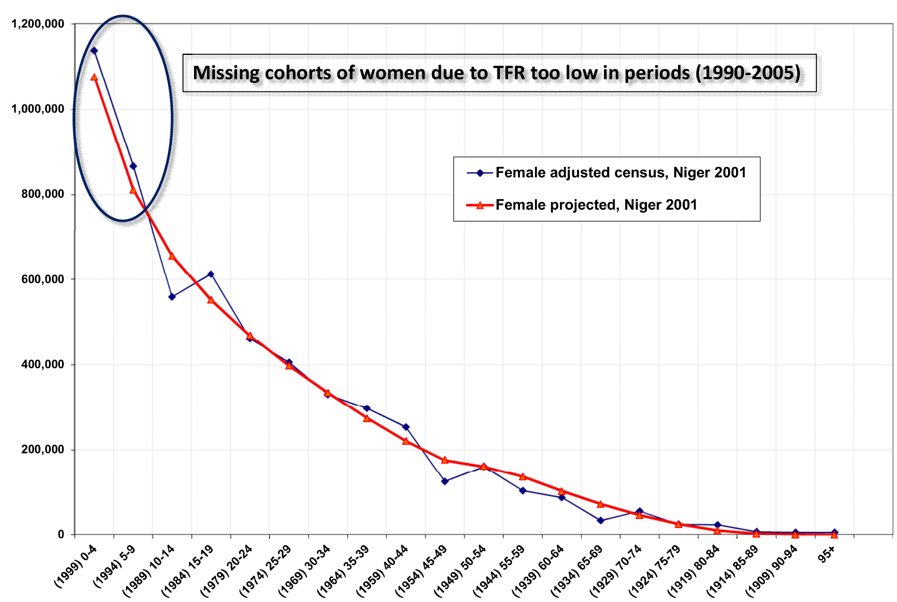
Further validation was conducted by comparing the population distribution by age and sex enumerated in each census with the reconstructed estimates produced by the Population Division. Figure I.6 provides a comparison of the female population for Niger plotted by 5-year age groups (and selected birth cohorts in parentheses) as enumerated in 2001 census (line with diamonds), and the UN reconstructed estimate (line with triangles) using an initial 1950 base population and subsequent trends in fertility, mortality and net international migration.

Figure I.6. Niger: comparison of the UN estimate and adjusted 2001 census female population by age groups



This figure illustrates the degree of fit between the official adjusted population from the 2001 census and the 2001 UN estimate based on a projection starting in 1950 using the fertility levels plotted in figure I.1. Particular care was taken to ensure that the projected population matched closely the census population in the first two age groups (0-4 and 5-9). The closeness of the match suggests that the adjusted UN fertility estimates are probably accurate for the 10 years prior to the 2001 census. Moreover, the figure suggests that the UN fertility and mortality estimates for the past 50 years are fairly consistent with the census cohorts. The difference in the age groups 10-14 and 45-49 is probably due to age-reporting errors in the census.

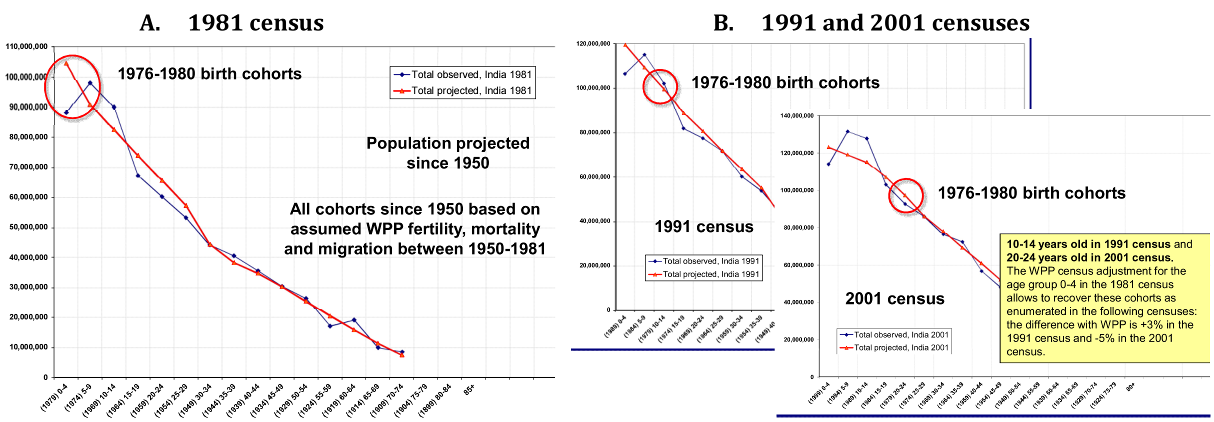
Figure I.7. Niger: comparison of a projection based on the "uncorrected" hypothetical TFR estimates and the adjusted 2001 census female population by age groups



On the contrary, figure I.7 above illustrates relatively large discrepancies between the census population and the estimated population when using the "uncorrected" hypothetical estimates of fertility.

When multiple successive censuses are available, like in the case of India, it is possible to track cohorts over time. This information can be used to assess the degree to which an apparent under-enumeration of children under the age of five reflected a real reduction in the size of the birth cohort or whether it was the result of age misreporting or date omission problems (Gerland, 2013). As seen in figure I.8, the size of the 1976-1980 birth cohorts in India as enumerated in 1981 census (panel A) was compared with the number of 10-14 year olds in the 1991 as well as the number of 20-24 year olds in the 2001 census (Panel B). Based on the UN adjusted estimates for the age group 0-4 (as compare to the 1981 census), the subsequent "projection" of these adjusted cohorts are fairly close to the enumerated populations in corresponding age groups within the 1991 and 2001 censuses. This suggests that the systematic under-enumeration of children under the age of 5, and somewhat over-reporting of children age 5-9 and 10-14 is a reporting artefact that disappears once children reach older ages.

Figure I.8. Comparison of India 1976-1980 birth cohorts enumerated in 1981, 1991 and 2001 censuses and 2012 revision estimates based on a 1950 population reconstruction



India 1976-1980 birth cohorts (circled) enumerated in 1981, 1991 and 2001 censuses (line with diamond) compared to projected cohorts based on WPP reconstruction (line with triangles) using an initial 1950 base population and subsequent trends in fertility, mortality and international migration.

4. *Checking consistency across countries*: Once all the various components of each country's estimates were calculated, the results were aggregated by geographical region and a final round of consistency checking took place, which involved comparing the preliminary estimates against those from other countries in the same region or at similar levels of fertility or mortality. "Outliers" and "crossovers" were identified and, if deemed necessary, further checks were applied to validate the preliminary estimates. An important component of the work at this stage is ensuring the consistency of information on net international migration, which for each 5-year period must sum to zero.

C. Data availability by demographic components

To provide some assessment of the timeliness of the information on which the *2012 Revision* is based, tables I.1a, b and c present information on the availability of recent demographic data in countries with 90,000 inhabitants or more in 2013.

As table I.1a indicates, this *Revision* incorporates relatively recent information on fertility for most countries: out of the 201 countries, 181 had information on fertility that referred to 2005 or later. This implies that information on recent levels of fertility was available for 99.7 per cent of the world's population. Similarly, for child mortality, measured as the probability of dying between birth and age five and a leading indicator that is used to assess the welfare of children, the availability of information is fairly up to date. Information on child mortality from 2005 or later was available for 181 countries, encompassing close to 95 per cent of the world's population (table I.1b).

In contrast with the availability of information on fertility and on child mortality, information on adult mortality is sparser and sometimes outdated (table I.1c). Data on adult mortality referring to 2005 or later was used in 106 countries and data from 2000-2004 was available for a further 19 countries. No empirical data on age-specific mortality was available or considered adequate for the estimation of adult mortality in 26 per cent of the countries, representing about 13 per cent of the world's population. Information was especially lacking or of insufficient quality among the countries of Africa. Consequently, life expectancy at birth was often derived by using recent information of infant and child mortality and appropriate model life tables. In addition, official estimates of adult mortality were sometimes considered, but not necessarily used because their quality was deemed inadequate. Thus, table I.1c reflects the data that was used in this *Revision*, not the availability of all possible data.

It is important to consider the implications of data availability on the quality of the population estimates and projections. One way of assessing the probable overall impact of the uncertainty involved in making estimates on the basis of non-existent or outdated information is to calculate the proportion of the population to which the less reliable or outdated estimates refer. With regard to information on fertility and child mortality, the population of countries that either lacked data entirely or whose most recently used estimates referred to periods before 2000 amounted to about 2 and 3 million people, respectively, which is quite small percentage-wise. However, the population lacking equally recent estimates of adult mortality amounted to over a billion person or 16 per cent of the world population. Therefore, the most serious weakness faced in producing the 2010 base year estimates of the population of each country was the lack of recent information on mortality, especially on adult mortality.

A final consideration in the *Revision* of past estimates of population dynamics concerns the sources of information regarding international migration. In preparing this *Revision,* particular attention was given to official estimates of net international migration or its components (immigration and emigration), to information on labour migration or on international migration flows recorded by receiving countries, to estimates of undocumented or irregular migration by origin, and to data about refugee stocks and flows prepared by the Office of the United Nations High Commissioner for Refugees. Even by combining these numerous data sources, it has been difficult to produce comprehensive and consistent data on net migration over time. Therefore, in several cases, net international migration was estimated as the residual not accounted for by natural increase between successive enumerations of a population. The paucity of reliable and comprehensive data on international migration is an important limitation to producing more accurate population estimates.

TABLE I.1a. DISTRIBUTION OF COUNTRIES AND POPULATION ACCORDING TO THE MOST RECENT DATA USED FOR THE ESTIMATION OF FERTILITY

Topic and reference date	*Africa*	*Asia*	*Europe and Northern America*	*Latin America and the Caribbean*	*Oceania*	*Total*
			Number of countries			
No Information	—	—	—	—	—	—
Before 1990	—	—	—	—	—	—
1990-1994	—	—	—	—	—	—
1995-1999	1	—	1	—	2	4
2000-2004	5	1	—	7	3	16
2005 or later	51	50	41	31	8	181
TOTAL	57	51	42	38	13	201
			Population (millions)			
No Information	—	—	—	—	—	—
Before 1990	—	—	—	—	—	—
1990-1994	—	—	—	—	—	—
1995-1999	1	—	—	—	1	2
2000-2004	13	1	—	3	—	18
2005 or later	1 017	4 164	1 086	593	35	6 896
TOTAL	1 031	4 165	1 086	596	36	6 915
			Percentage of the population			
No Information	—	—	—	—	—	—
Before 1990	—	—	—	—	—	—
1990-1994	—	—	—	—	—	—
1995-1999	0.1	—	—	—	3.0	—
2000-2004	1.3	—	—	0.5	1.0	0.3
2005 or later	98.6	100.0	100.0	99.5	96.0	99.7
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

Table I.1b. Distribution of countries and population according to the most recent data used for the estimation of child mortality

Topic and reference date	*Africa*	*Asia*	*Europe and Northern America*	*Latin America and the Caribbean*	*Oceania*	*Total*
			Number of countries			
No Information	1	—	—	—	—	1
Before 1990	—	—	—	—	—	—
1990-1994	—	—	—	—	—	—
1995-1999	1	0	1	1	2	5
2000-2004	4	4	—	3	3	14
2005 or later	51	47	41	34	8	181
Total	57	51	42	38	13	201
			Population (millions)			
No Information	1	—	—	—	—	1
Before 1990	—	—	—	—	—	—
1990-1994	—	—	—	—	—	—
1995-1999	1	—	—	—	1	3
2000-2004	23	134	—	212	1	370
2005 or later	1 006	4 032	1 086	384	34	6 542
Total	1 031	4 165	1 086	596	36	6 915
			Percentage of the population			
No Information	—	—	—	—	—	—
Before 1990	—	—	—	—	—	—
1990-1994	—	—	—	—	—	—
1995-1999	0.1	—	—	0.1	3.8	—
2000-2004	2.3	3.2	—	35.5	1.6	5.3
2005 or later	97.6	96.8	100.0	64.4	94.6	94.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table I.1c. Distribution of countries and population according to the most recent data used for the estimation of adult mortality

Topic and reference date	*Africa*	*Asia*	*Europe and Northern America*	*Latin America and the Caribbean*	*Oceania*	*Total*
			Number of countries			
No Information	34	7	—	6	5	52
Before 1990	2	—	—	1	1	4
1990-1994	1	6	1	3	1	12
1995-1999	1	3	1	1	2	8
2000-2004	6	5	3	4	1	19
2005 or later	13	30	37	23	3	106
Total	57	51	42	38	13	201
			Population (millions)			
No Information	589	284	—	11	1	884
Before 1990	38	—	—	1	1	39
1990-1994	11	132	11	5	—	159
1995-1999	9	12	—	—	8	29
2000-2004	27	1 496	11	218	—	1 753
2005 or later	357	2 241	1 064	362	27	4 050
Total	1 031	4 165	1 086	596	36	6 915
			Percentage of the population			
No Information	57.1	6.8	—	1.8	2.0	12.8
Before 1990	3.7	—	—	0.1	1.4	0.6
1990-1994	1.1	3.2	1.0	0.8	0.4	2.3
1995-1999	0.9	0.3	0.0	0.0	21.2	0.4
2000-2004	2.7	35.9	1.0	36.6	0.7	25.4
2005 or later	34.6	53.8	97.9	60.7	74.2	58.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

II. THE PREPARATION OF POPULATION PROJECTIONS

The Population Division has employed the cohort-component projection method for producing individual country projections since the *1963 Revision*. This method, the most common projection method used by demographers, provides an accounting framework for the three demographic components of change — births, deaths and international migration — and applies it to the population affected. Technically, it is not a projection method, as it requires that all the components of change — births, deaths, and migration — be projected in advance. Rather, it is an application of matrix algebra that enables demographers to calculate the effect of assumed future patterns of fertility, mortality, and migration on a population at some given point in the future (see Preston et al., 2001).

The future population of each country was projected from 1 July 2010. Because population data was not available for that date for all countries of the world, the 2010 estimate was derived from the most recent population and demographic data available. To project the population until 2100, the United Nations Population Division used various assumptions regarding future trends in fertility, mortality and international migration. Because the future is uncertain, a number of different projection variants were produced to convey the sensitivity of the projections to changes in the underlying assumptions. The following paragraphs summarize the assumptions used for each of the different variants.

A. FERTILITY ASSUMPTIONS: CONVERGENCE TOWARD LOW FERTILITY

The fertility assumptions are described in terms of the following groups of countries:

- *High-fertility countries*: Countries that until 2010 had no fertility reduction or only an incipient decline;
- *Medium-fertility countries*: Countries where fertility has been declining but whose estimated level is above the replacement level of 2.1 children per woman in 2005-2010;
- *Low-fertility countries*: Countries with total fertility at or below the replacement level of 2.1 children per woman in 2005-2010.

1. Medium-fertility assumption

The *2012 Revision* of the *World Population Prospects* used the same probabilistic method for projecting total fertility as the *2010 Revision* with two notable enhancements. First, the new revision of the model has incorporated the latest information from the 2010 round of censuses as well as from newly-available surveys. Second, once countries reach below-replacement fertility, the long-term fertility assumption is now more data-driven and country-specific. The method for producing long-term fertility projections was developed in collaboration with the Probabilistic Projections Group of the Center for Statistics and the Social Sciences (CSSS) of the University of Washington, and the Department of Statistics and Applied Probability and Saw Swee Hock School of Public Health of the National University of Singapore (Alkema et al., 2011; Raftery et al., 2009; Raftery, Alkema and Gerland, 2013). The method utilizes the fertility levels and trends estimated for the *2012 Revision* for all countries[6] of the world for the period 1950 to 2010 (or up to 2010-2015 for 37 countries with empirical data up to 2011 or 2012).

There is general consensus that the evolution of fertility includes three broad phases (see figure II.1 and further details below): (i) a high-fertility pre-transition phase, (ii) a fertility transition phase, and, (iii) a low-fertility post-transition phase. During the third, post-transition, phase, fertility will probably fluctuate around or below 2.1 children per woman. These historic trends of fertility decline are re-estimated every second year by the United Nations Population Division, using the most recent empirical evidence from censuses, surveys, registers and other sources and after extensive re-evaluation of past historical trends in the light of all the information available and internal consistency checks with intercensal cohorts.

[6] Only countries or areas with 90,000 persons or more in 2013 are considered.

In past revisions of the *World Population Prospects* it was assumed that countries in the transition from high to low fertility would ultimately approach a fertility floor of 1.85 children per woman, regardless of their current position in the fertility transition. The transition from the current level of fertility to the fertility floor was expressed by three models of fertility change over time. These fertility projection models have been formalized since the *2004 Revision* using a double-logistic function, defined by six deterministic parameters (United Nations, 2010). For countries that were below replacement level, a much simpler model of fertility change was used. In general, it was assumed that fertility would recover from very low levels of fertility, following a uniform pace that would also converge to the fertility floor of 1.85 children per woman, just as in the high and medium fertility countries.

The probabilistic method used in the *2010 and 2012 Revisions* for projecting total fertility consisted of two separate processes:

The first process models the sequence of change from high to low fertility (phase II of the fertility transition). For countries that are undergoing a fertility transition, the pace of the fertility decline is decomposed into a systematic decline and various random distortion terms. The pace of the systematic decline in total fertility is modelled as a function of its level, based on a double-logistic decline function. The parameters of the double-logistic function were estimated using a Bayesian Hierarchical Model (BHM), which results in country-specific *distributions* for the parameters of the decline. These distributions are informed by historical trends within the country, as well as the variability in historical fertility trends of all countries that have already experienced a fertility decline. This approach not only allows one to take better into account the historical experience of each country, but also to reflect the uncertainty about future fertility decline based upon the past experience of all other countries at similar levels of fertility. Under the model, the pace of decline and the limit to which fertility was able to decline in the future varied for each projected trajectory. The model is hierarchical because in addition to the information available at the country level, a second-level (namely, the world's experience through the information of all countries) is also used to inform the statistical distributions of the parameters of the double-logistic function. This is particularly important for countries at the beginning of their fertility transition because limited information exists as to their speed of decline. Thus, their future potential trajectories (and speed of decline) are mainly informed by the world's experience and the variability in trends experienced in other countries at similar levels of fertility in the past. The Bayesian statistical approach itself is particularly suitable for estimating the parameters of a double-logistic model even when the number of empirical observations for each country is very limited.

The second component of the projection model deals with countries once they have completed the demographic transition, and have reached Phase III of low fertility. For these countries, a time series model was used to project fertility that assumed that in the long run fertility would approach and fluctuate around country-specific ultimate fertility levels based on a Bayesian hierarchical model (Raftery et al., 2013). The time series model uses the empirical evidence from low-fertility countries that have experienced fertility increases from a sub-replacement level after a completed fertility transition. Future long-term fertility levels in the *2012 Revision* are now country-specific and have been informed by statistical distributions that have incorporated the empirical experience of all low-fertility countries which had already experienced a recovery. This differs from the more normative assumption used in the *2010 Revision* that assumed a global replacement-level of 2.1 children per woman in the very long-term[7]. This new approach not only enables a better accounting of the historical experience of each country, but also reflects the variability in historical fertility trends of all low-fertility countries and the uncertainty about the pace of a potential fertility recovery and long-term fertility levels. The world mean parameter for the country-specific asymptotes is now restricted to be no greater than the replacement level of 2.1 children per woman. [8]

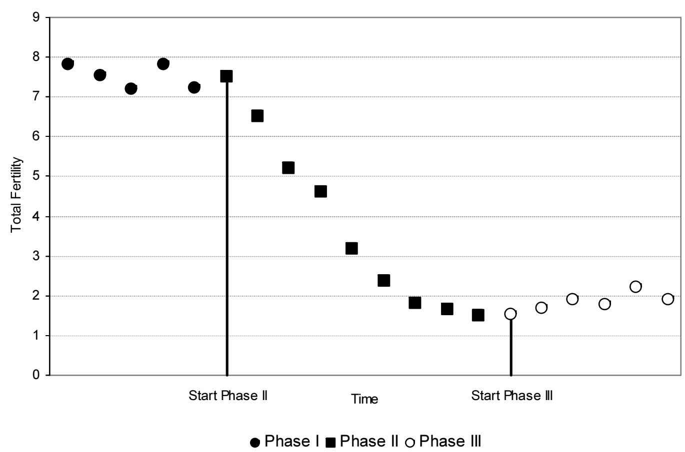
[7] It should be noted that within the *2010 Revision* most low-fertility countries did not reach replacement level by 2100.

[8] While the asymptote does not have an explicit lower bound, it does implicitly because any given total fertility trajectory is restricted not to be smaller than 0.5 child.

While the long-term assumption of a fertility increase is supported by the experience of many low-fertility countries in Europe and East Asia (Bongaarts and Sobotka, 2012; Caltabiano, Castiglioni, and Rosina, 2009; Goldstein, Sobotka and Jasilioniene, 2009; Myrskylä, Goldstein and Cheng, 2013; Myrskyla, Kohler and Billari, 2009; Sobotka, 2011), the new approach additionally draws upon the specific experience of each country. In this approach, countries that had experienced extended periods of low fertility with no empirical indication of an increase in fertility, were projected to continue at low fertility levels in the near future, as the research on "low fertility trap hypothesis" has argued for some low-fertility countries in Europe (Lutz, 2007; Wolfgang, Skirbekk and Testa, 2006) and East Asia (Basten, 2013; Frejka, Jones and Sardon, 2010; Jones, Straughan and Chan, 2008).

The two processes described above are represented in figure II.1. During the observation period, the start of Phase II is determined by examining the maximum total fertility (or more precisely, the most recent local maximum within half a child of the global maximum to exclude random fluctuations in Phase I): the start of Phase II is deemed to be before 1950 for countries where this maximum is less than 5.5, and at the period of the local maximum for all other countries. The end of Phase II during the observation period is defined as the midpoint of the first two increases below 2 (if observed, else a country is still in Phase II).

Figure II.1. Schematic phases of the fertility transition



Phase I: High-fertility pre-transition phase. **Not modelled.**

Phase II. Fertility transition phase, **modelled by double-logistic function using a Bayesian Hierarchical Model (BHM)**.

Phase III. Low-fertility post-transition phase, **modelled with a first order auto-regressive time series model (AR(1)) in Bayesian Hierarchical framework.**

Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2013). *World Population Prospects: The 2012 Revision.* New York: United Nations.

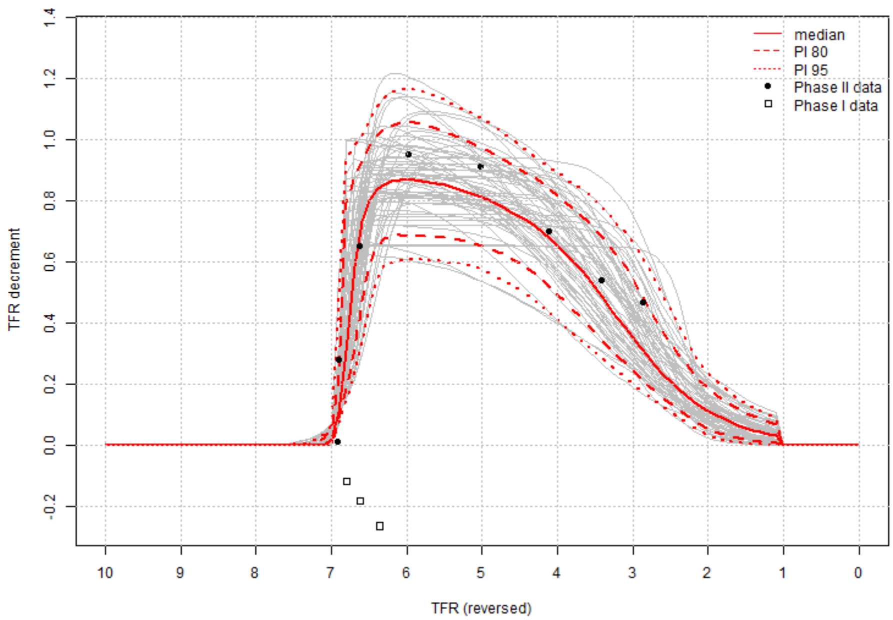
To construct projections for all countries still in Phase II, the Bayesian Hierarchical Model (BHM) model was used to generate 600,000[9] double-logistic curves for all countries that have experienced a fertility decline (see example in figure II.2), representing the uncertainty in the double-logistic decline function of those countries[10]. The sample of double-logistic curves is then used to calculate 60,000 total fertility projections for all countries that have not reached Phase III by 2005-2010. For each trajectory, at any given time, the double-logistic function provides the expected decrement in total fertility based on its current level. A distortion term is added to the expected decrement to calculate the projected change in total fertility.

Once a trajectory has decreased to a level that is around or below replacement-level fertility, and after the pace of the fertility decline has decreased to zero, future changes of fertility are calculated using a time series model of fertility recovery that is informed by the countries that have experienced fertility increases.

[9] Actually ten simulations are run in parallel with 62,000 iterations performed for each simulation, and the first 2,000 are discarded.
[10] Graphs of this double-logistic curve are available online at: http://esa.un.org/unpd/wpp/fertility_figures/interactive-figures_DL-functions.htm.

An additional innovation starting in the *2010 Revision* of the *World Population Prospects* was the removal of the 1.85 floor for total fertility, which was used in previous revisions as the stabilization level after the fertility transition had occurred. Therefore, the total fertility is now allowed to fall *below* that threshold in the projections because of the uncertainty related to the level to which fertility would decline (at the end of Phase II) before it started to recover (at the start of Phase III). The pace of the fertility change, the level and timing when Phase II stops and Phase III starts varies for each of the 600,000 projected trajectories of change in fertility for a country that has not reached Phase III by 2005-2010. Future trajectories are a combination of total fertility in Phases II and III until all trajectories are in Phase III. For countries that are already in Phase III, the time series model for that phase is used directly.

Figure II.2. Total fertility decrements and projection intervals of double-logistic curves for Bangladesh (systematic decline part)



NOTE: The observed five-year decrements by level of total fertility are shown by black dots. For clarity, only 60 trajectories from 600,000 are displayed. The median projection is the solid bold red line, and the 80 per cent and 95 per cent projection intervals are displayed as dashed and dotted red lines respectively.

By systematically sampling one in ten of the 600,000 simulated trajectories produced by this process, the end result was 60,000 projected trajectories of total fertility for each country. The median of these 60,000 trajectories is used as the medium fertility variant projection in the *World Population Prospects*. To evaluate future trends in fertility, 80 per cent and 95 per cent projection intervals were also calculated (see figure II.3 for Bangladesh; additional tables[11] and graphs[12] are available online for all countries). For countries which have not reached Phase III by 2005-2010, the projected median trajectory reflects the uncertainty as to when the fertility transition will end and at which level.

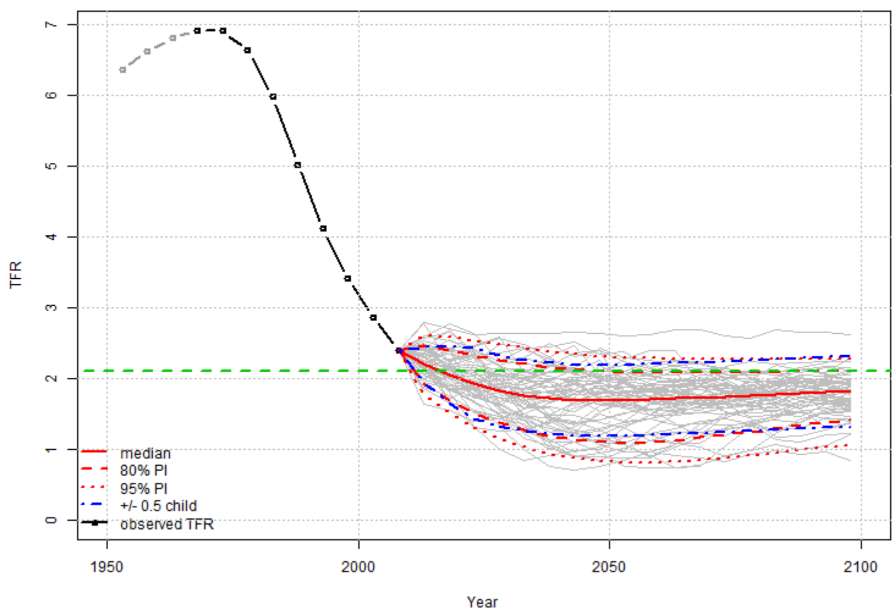
[11] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online tables of stochastic projections of total fertility: median, 80% and 95% projection intervals http://esa.un.org/unpd/wpp/fertility_figures/data/WPP2012_FERT_PPP_Total_Fertility.xls.

[12] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of projections of total fertility: median, 80% and 95% projection intervals, high and low WPP fertility variants: http://esa.un.org/unpd/wpp/fertility_figures/interactive-figures_TF-trajectories.htm.

a. *Caveat about medium-high fertility countries experiencing slower declines than expected or even stalling*

The *2012 Revision* drew on new empirical evidence on fertility levels and trends that became available since the publication of the *2010 Revision*. The empirical evidence from available surveys and the 2010 round of censuses has provided the basis for a reassessment of fertility levels and trends experienced within the last decade. In a number of countries, particularly in Africa, slower than expected fertility declines or even stalled fertility was observed. In some cases, increases in total fertility were also recorded. This led to the decision not to apply the additional adjustment that was used in the *2010 Revision* for a small number of countries at the very early stage of their fertility transition (for example, Mali, Niger, Nigeria, and Somalia) or that had experienced recent fertility stalling (for example, Congo, Gabon, Kenya, Malawi, Mozambique, Rwanda, Sao Tome and Principe, United Republic of Tanzania, Zambia, and Zimbabwe). For these countries, the recent fertility decline has been much slower than typically experienced in the past decades by other countries at similar levels of fertility, and the additional adjustment would have delayed any potential future decline, implying even more population growth than already anticipated with the standard assumption.

Figure II.3. Probabilistic trajectories of projected total fertility (2010-2100) for Bangladesh

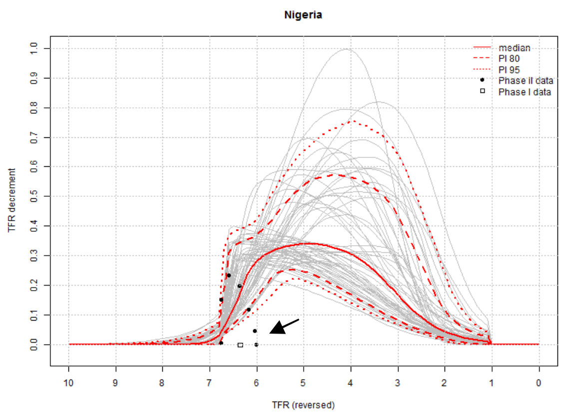


NOTE: For clarity, only 60 trajectories from 60,000 are displayed. The median projection is the solid bold red line, and the 80 per cent and 95 per cent projection intervals are displayed as dashed and dotted red lines respectively. The high-low fertility variants in the *2012 Revision* correspond to +/- 0.5 child around the median trajectory displayed as blue dashed lines. The replacement-level of 2.1 children per woman is plotted as green horizontal dashed line only for reference.

The fertility projections for sub-Saharan Africa followed the general path from high to low fertility observed in other regions. More specifically, the projections for sub-Saharan Africa were informed by fertility changes observed since 1950 in countries in Asia and Latin America and the Caribbean as well as in other African countries that were further advanced in their fertility transition. This assumption is perhaps optimistic in the face of the recent empirical evidence (Bongaarts and Casterline, 2013) as it assumes that, in the long term, all sub-Saharan African countries will follow the same general path from high to low fertility that was experienced in all other regions, albeit at a slower pace and through a different combination of factors (in terms of patterns of female education, union formation, length of birth intervals, ideal number of children, adoption of modern contraceptive methods and so on).

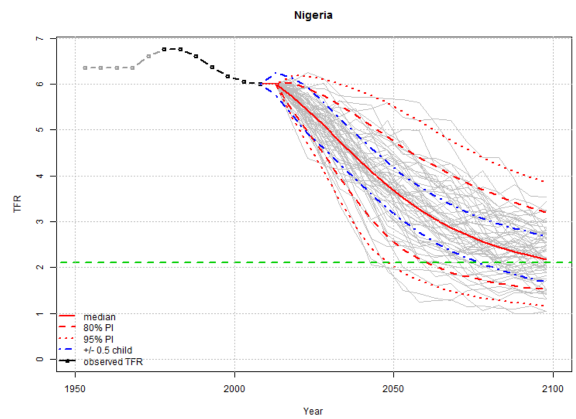
In Nigeria, the empirical record suggests that fertility decline has stalled at around 6 children per woman for the past decade: the decline between 2000-2005 and 2010-2015 was estimated to be smaller than in previous periods (figure II.4), especially compared to other countries when they were at a similar level of fertility in the past. The fertility projections reflect a long-term trend that was informed both by the past changes in fertility in Nigeria, as well as by the experience of other countries under similar conditions (figure II.5). In the case of Nigeria, the level of uncertainty about the true level and trend in total fertility is large, as can be seen between the various strands of empirical evidence on fertility that was made available from different sources and when different methodologies were applied (see figure II.6 for Nigeria).

Figure II.4. Total fertility decrements and projection intervals of double-logistic curves for Nigeria



NOTE: The black dots represent the observed decrements, which are much smaller than the double-logistic-decrements in the last two observation periods (2005-2015) because of a stall in the fertility decline. For clarity, only 60 trajectories from 60,000 are displayed

Figure II.5. Probabilistic trajectories of projected total fertility (2015-2100) for Nigeria



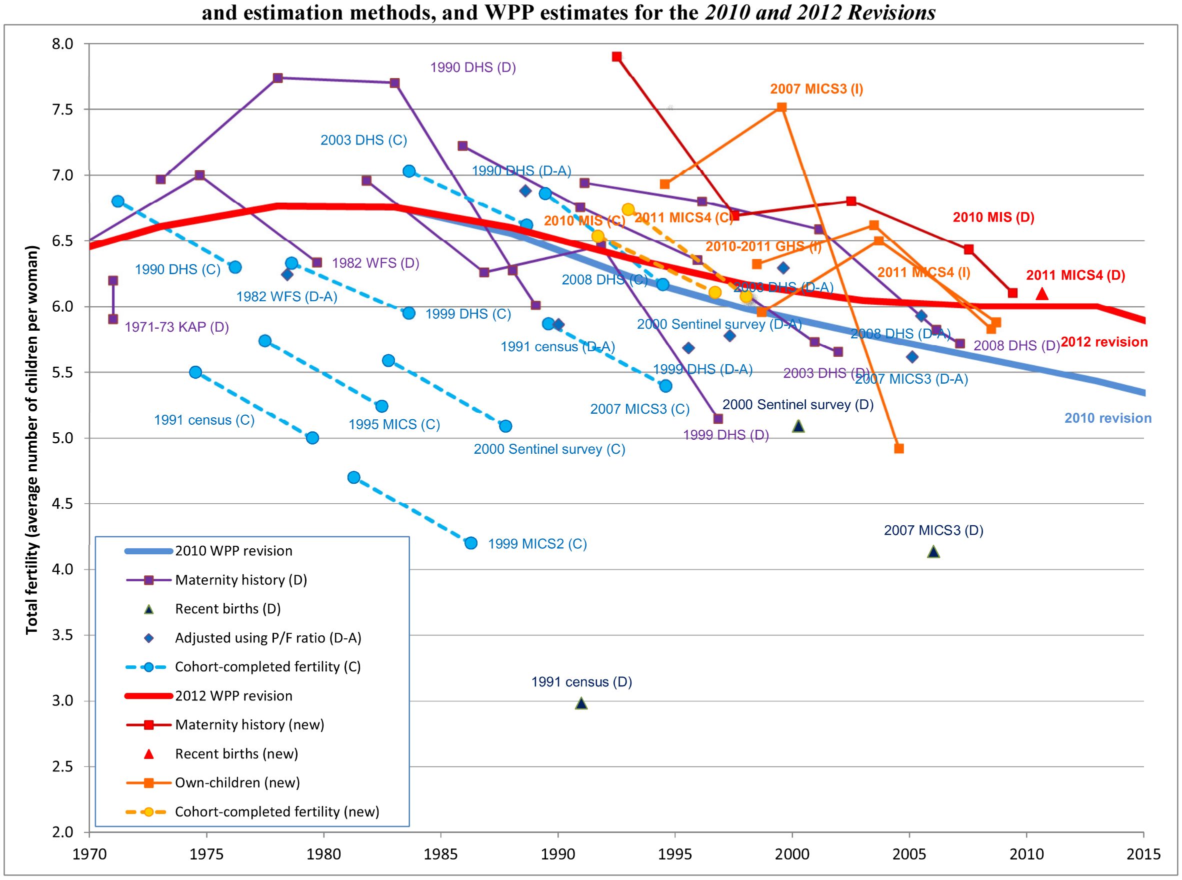
NOTE: For clarity, only 60 trajectories from 60,000 are displayed. The median projection is the solid bold red line, and the 80 per cent and 95 per cent projection intervals are displayed as dashed and dotted red lines respectively. The high-low fertility variants in the *2012 Revision* correspond to +/- 0.5 child around the median trajectory displayed as blue dashed lines. The replacement-level of 2.1 children per woman is plotted as green horizontal dashed line only for reference.

In figure II.6, all empirical evidence used to derive total fertility estimates for the period 1970 to 2010 in Nigeria are shown in blue for the *2010 Revision*. Multiple data sources were considered, and one or multiple estimation methods were used for some of them. These methods included: (a) direct estimates based on maternity-history data adjusted for underreporting from the 1981-1982 Nigeria World Fertility Survey (WFS), 1990, 1999, 2003 and 2008 Demographic and Health Surveys (DHS), (b) recent births in the preceding 12 months (or 36 months) by age of mother, from these surveys and from the 1971-1973 National Fertility, Family Planning and Knowledge, Attitudes and Practices survey, 1991 census, 2000 Nigeria Sentinel Survey, 2007 Multiple Indicator Cluster Survey (MICS 3); (c) adjusted fertility using Brass P/F ratio (United Nations, 1983) and data on children ever born from these sources; and, (d) cohort-completed fertility[13] from these surveys and censuses, and the 1995 MICS and 1999 MICS2 surveys.

Since the *2010 Revision*, results from several new surveys became available and were considered in addition to those previously used. More specifically, the 2010 Malaria Indicator Survey (MIS) provided maternity-history data covering the retrospective period 1990-2010, the 2011 Multiple Indicator Cluster Survey (MICS4) provided fertility on the 12-months preceding the survey, and microdata available for the MICS4 survey as well as the previous 2007 Multiple Indicator Cluster Survey (MICS3) and 2010-2011 General Household Survey (GHS) enabled the computation of indirect fertility estimates using the own-children method. These additional estimates are shown in red in figure II.6 together with the 2012 WPP estimates. As can be seen in the figure, the estimate of fertility in Nigeria needed to be revised upward once the new information was taken into account.

[13] Using Ryder's (1964, 1983) correspondence between period and cohort measures, the mean number of children ever born (CEB) to a cohort is used to approximate the period total fertility rate at the time this cohort was at its mean age at childbearing. See Feeney (1995, 1996) for further details about time translation of mean CEB for women age 40 and over.

Figure II.6. Nigeria 1970-2015 total fertility rate estimates based on various data sources and estimation methods, and WPP estimates for the *2010 and 2012 Revisions*



As stated above and contrary to what was done in the *2010 Revision*, no additional adjustment was made to compensate for differences between the observed and the expected decrement in fertility within the most recent period. In the *2012 Revision*, the recent stagnation was treated as a temporary phenomenon because of the inherent uncertainty in these countries. Recent global and country-specific investments to accelerate access to modern contraceptive methods in the poorest countries of the world provide further reason to consider a slowdown in the pace of fertility decline as transitory (London Summit on Family Planning, 2012).

The fertility projections produced in the *2012 Revision*, were informed by historical trends in fertility and rely on the implicit assumption that the conditions facilitating fertility decline will persist in the future. Should massive efforts to scale up family planning information, supplies and services be realized, then the fertility projections may be too high. On the other hand, should prevailing conditions underlying fertility decline deteriorate (for example, if there is a slowdown in modern contraceptive method uptake or a persistent desire for early marriage and large families), then the fertility projections may be too low.

b. Long-term ultimate fertility level once countries reach low fertility

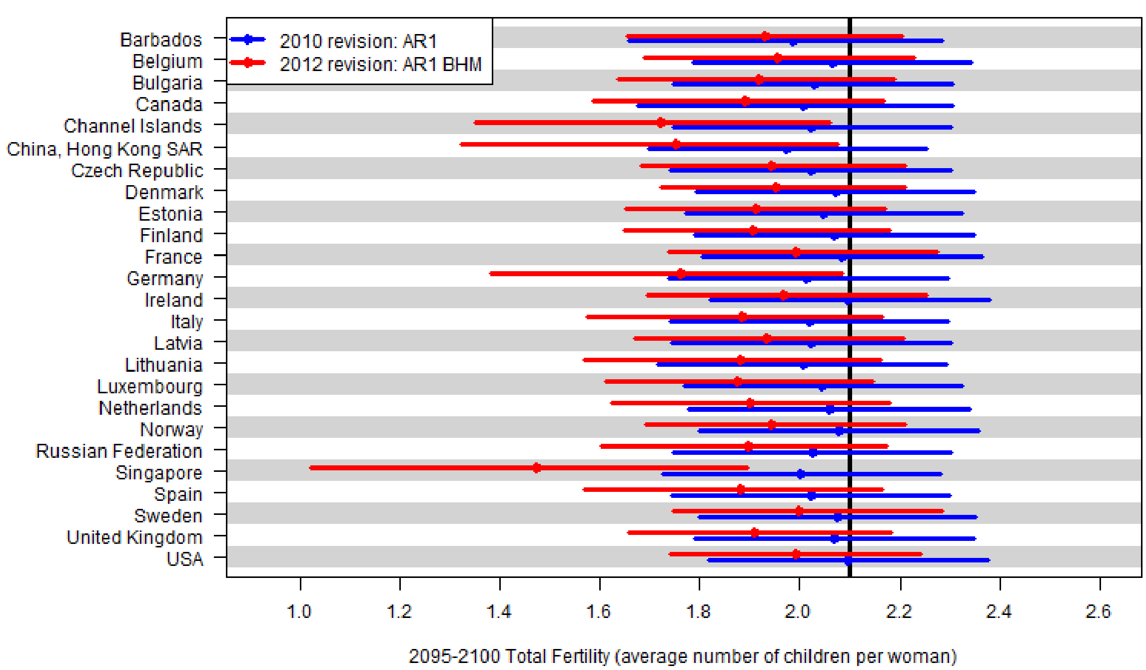
Empirical evidence suggests that at least 25 countries or areas with total fertility below replacement at some point between 1950 and 2010 have experienced slight increases in fertility after they had reached their lowest level. The revised hierarchical autoregessive model (AR1) used for low fertility countries uses the information on the rates of change in total fertility from countries that have experienced at least two consecutive data points of (slight) increase in total fertility. Table II.1 provides a list of these countries and the five-year interval before the start of Phase III (approximated by the midpoint of the earliest two periods with subsequent increases below a TFR of 2.1) was reported:

TABLE II.1. LOW-FERTILITY COUNTRIES HAVING EXPERIENCED SOME INCREASE IN AT LEAST TWO CONSECUTIVE PERIODS

Country or area	*Lowest level of total fertility before start of Phase III*	*Region*	*Country or area*	*Lowest level of total fertility before start of Phase III*	*Region*
Barbados	1990-1995	Caribbean	Italy	1995-2000	Southern Europe
Belgium	1995-2000	Western Europe	Latvia	1995-2000	Northern Europe
Bulgaria	1995-2000	Eastern Europe	Lithuania	2000-2005	Northern Europe
Canada	2000-2005	Northern America	Luxembourg	1980-1985	Western Europe
Channel Islands	1980-1985	Northern Europe	Netherlands	1980-1985	Western Europe
China, Hong Kong SAR	1995-2000	Eastern Asia	Norway	1980-1985	Northern Europe
Czech Republic	1995-2000	Eastern Europe	Russian Federation	1995-2000	Eastern Europe
Denmark	1980-1985	Northern Europe	Singapore	1980-1985	South-Eastern Asia
Estonia	1995-2000	Northern Europe	Spain	1995-2000	Southern Europe
Finland	1970-1975	Northern Europe	Sweden	1995-2000	Northern Europe
France	1990-1995	Western Europe	United Kingdom	1975-1980	Northern Europe
Germany	1990-1995	Western Europe	United States of America	1975-1980	Northern America
Ireland	1990-1995	Northern Europe			

Country-specific ultimate fertility levels under the new AR1 hierarchical model are now smaller for low-fertility countries as compare to the *2010 Revision* projected levels, though by no more than 0.25 of a child for most countries. For 23 of the 25 countries, the 2010 projections are within the 80 per cent projection intervals (PIs), as constructed based on the new AR1 hierarchical model (figure II.7). For the period 2095-2100, the average median total fertility for these countries is projected to be 1.89 (80 per cent projection interval 1.59-2.17) instead of 2.04 (80 per cent projection interval 1.76-2.32). The main exception is Singapore, where the projection under the hierarchical model is much lower, with the median fertility level estimated to only reach 1.5 instead of 2.0 by 2095-2100.

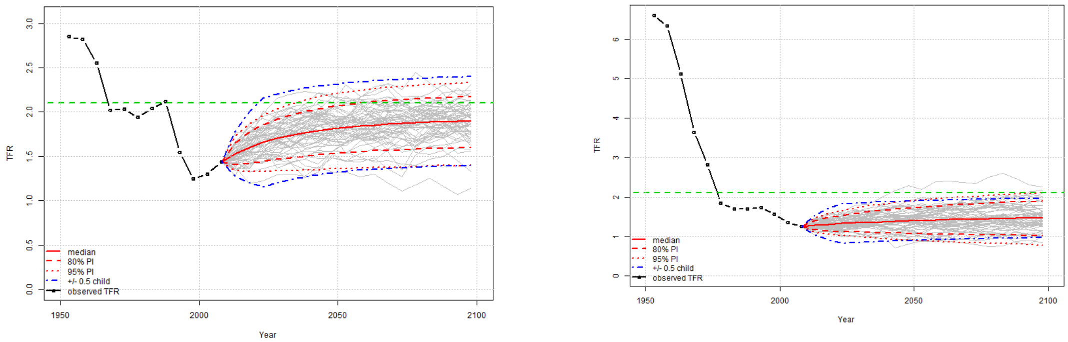
Figure II.7. Comparison of total fertility projections for 2095-2100 with 80 per cent projection intervals between the *2010 and 2012 Revisions* for 25 low-fertility countries used to estimate the AR1 Bayesian Hierarchical Model (BHM)



The effect of the new AR1 hierarchical model varied for each low-fertility country depending on its past experience as can be seen in figure II.8 for the Russian Federation and Singapore.

Figure II.8. Projections of total fertility with 80 per cent and 95 per cent projection intervals for selected low-fertility countries

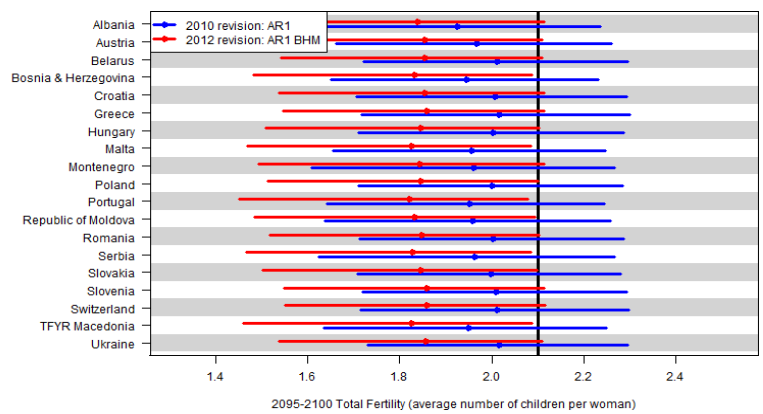
Panel A. Russian Federation **Panel B. Singapore**



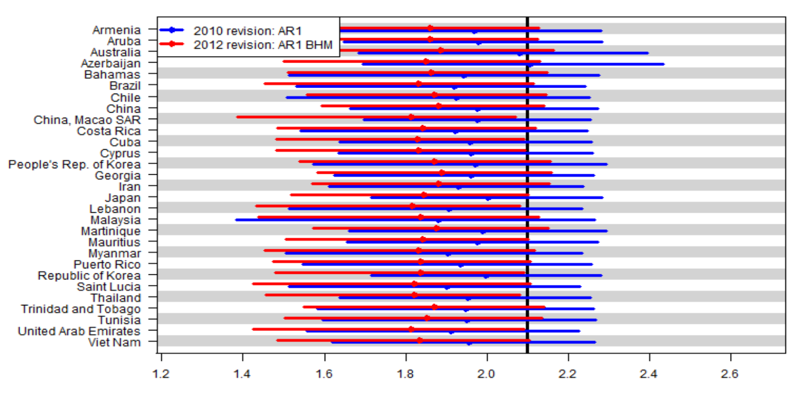
The new AR1 hierarchical model has projected only small differences in total fertility by 2095-2100, between the *2010* and *2012 Revisions,* for the 50 other countries or areas experiencing low fertility in 2005-2010 with no significant sign of increase in at least two consecutive periods. In all instances, the 2012 projections compared to the *2010 Revision* are slightly lower (on average by about 0.1 child) as seen in figure II.9 with an average median fertility level of 1.85 (80 per cent projection interval 1.5-2.1).

Figure II.9. Comparison of total fertility projections for 2095-2100 with 80 per cent projection intervals between the *2010 and 2012 Revisions* for all low-fertility countries in 2005-2010 not having experienced any increase in at least two consecutive periods between 1950-2010

Panel A: European countries



Panel B: Countries or areas in other regions



Overall, the majority of countries (including among those in 2005-2010 still experiencing medium-high fertility) were assumed to experience low fertility sometime between 2010 and 2100 (see figure II.10 right-lower quadrant B).

Figure II.10. Timing when countries reach lowest median total fertility

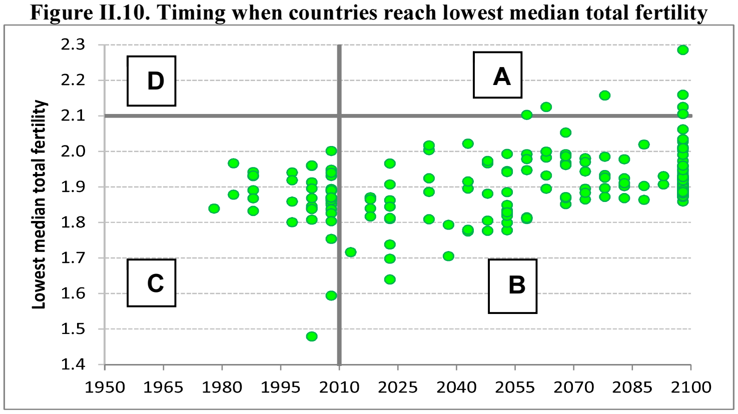
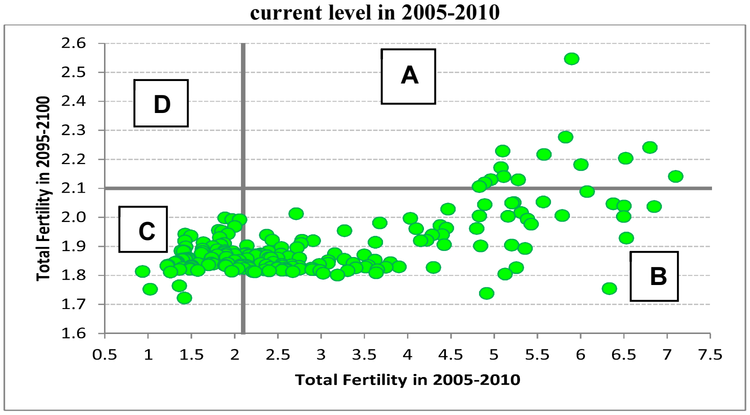


Figure II.11 shows the relationship between the total fertility estimates for the 2005-2010 period and the median projection for the 2095-2100 period:

A. There were only 15 countries with fertility above 2.1 in 2005-2010, which were projected to have fertility levels still above 2.1 children per woman in 2095-2100 (right-upper quadrant A).
B. Most of the high and medium fertility countries in 2005-2010 were projected to have fertility levels below 2.1 children per woman in 2095-2100 (right-lower quadrant B).
C. Almost all low-fertility countries (below 2.1 children per woman) in 2005-2010 were projected to still have a fertility of below 2.1 children per woman in 2095-2100 (left-lower quadrant C)
D. There was not a single country with below-replacement fertility in 2005-2010, for which the fertility level is projected to be above 2.1 children per woman in 2095-2100 (left-higher quadrant D).

Figure II.11. Median projection of total fertility by 2095-2100 compared to current level in 2005-2010



In summary the *2012 Revision* did not impose any long term convergence toward a replacement level of 2.1 children per woman for all countries. Future long-term fertility levels were country-specific, and informed by statistical distributions that incorporated the empirical experience of all 25 low-fertility countries that had experienced some increase in fertility in at least two consecutive periods.

The results of this new modelling approach are country-specific projections of total fertility that are fully reproducible and take into account past empirical trends. Extensive documentation for all countries and areas has been posted online[14], and further details about the methodology are contained in Alkema et al. (2011) and Raftery et al. (2013). In addition, an open-source and portable software implementation of the UN approach to project total fertility, based on the R statistical language, has been developed by Sevcikova et al. (2011) and is available as a fully documented R package (bayesTFR[15]) through the public R CRAN archive together with a user-friendly Graphical User Interface (bayesDem[16]), and the full dataset used for the *2012 Revision*[17]. Version 3.0-9 of the bayesTFR package was used to compute the final set of projections used for the *2012 Revision* of the *World Population Prospects*[18].

c. Projection of the age pattern of fertility

Once the path of future total fertility was determined, age-specific fertility rates by five-year age group, consistent with the total fertility for each quinquennium were calculated.

For both the high-fertility and the medium-fertility countries, the age pattern of fertility was projected by interpolating linearly between a starting proportionate age pattern of fertility and a target model pattern. The target pattern was usually attained in either 2045-2050 or in the period when the country reached its lowest fertility level. In several cases, the proportionate age pattern of fertility was held constant thereafter. Model age patterns of fertility for high- and medium-fertility countries used for projection are presented in table II.2 as proportionate age-specific fertility, indexed by the mean age at childbirth. Projected age-specific fertility rates were obtained by applying the projected total fertility levels to these age patterns of fertility.

TABLE II.2. MODEL FERTILITY SCHEDULES FOR HIGH AND MEDIUM-FERTILITY COUNTRIES

	Percentage of total fertility by age group								
Model	*15-19*	*20-24*	*25-29*	*30-34*	*35-39*	*40-45*	*45-49*	*Total*	*Mean age at childbirth*
1	18	49	23	8	2	0	—	100	24.0
2	16	46	28	8	2	0	—	100	24.3
3	9	43	31	12	4	1	—	100	25.6
4	7	44	29	15	5	1	—	100	26.0
5	11	37	29	17	6	1	—	100	26.2
6	5	39	34	15	6	1	—	100	26.6
7	12	30	31	18	8	2	—	100	26.7
8	5	37	34	17	6	1	—	100	26.8
9	12	28	33	19	7	1	—	100	26.8
10	3	34	36	18	7	1	—	100	27.3
11	1	28	48	19	4	1	—	100	27.5
12	1	24	55	17	3	1	—	100	27.5
13	2	27	42	20	7	1	—	100	27.9
14	5	23	38	24	10	2	—	100	28.3
15	2	23	40	24	9	2	—	100	28.5

[14] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of projections of total fertility: median, 80% and 95% projection intervals, high and low WPP fertility variants: http://esa.un.org/unpd/wpp/fertility_figures/interactive-figures_TF-trajectories.htm.

[15] Sevcikova H., L. Alkema, A.E. Raftery (2013). bayesTFR: Bayesian Fertility Projection. *R Package and documentation*: http://cran.r-project.org/web/packages/bayesTFR/

[16] Sevcikova H. (2013). bayesDem: Graphical User Interface for bayesTFR and bayesLife. *R Package and documentation*: http://cran.r-project.org/web/packages/bayesDem/.

[17] Sevcikova H. et al. (2013). wpp2012: World Population Prospects 2012. *R Package and documentation*: http://cran.r-project.org/web/packages/wpp2012/.

[18] The estimates of the double logistic parameters are based on ten parallel chains of 62,000 iterations discarding the first 2,000 of each chain to yield a total of 600,000 samples of all model parameters. For each country, 100,000 trajectories were projected, and used to derive the median and other projection intervals. Total computation time was about 1 day on a 64-bit Windows 7 workstation with multicore processors. The seed of the random number generator for the Markov Chain Monte Carlo estimation used was: 20130523.

For low-fertility countries, proportionate age-specific fertility rates for the projection period were obtained by either (a) extrapolating the most recent set of proportionate age-specific fertility rates by the rates of change from country-specific historical trends, upon reliability and consistency over time, using a modified Lee-Carter approach (Li and Gerland, 2009), or (b) interpolating linearly between the most recent age pattern of fertility available and a model age-specific pattern to be reached in general by 2025-2030. Once the model pattern is reached, it is assumed to remain constant until the end of the projection period. In both instances additional constraints might have been used at younger ages to insure greater consistency between countries, especially at very low levels of projected fertility.

The model age patterns of fertility for low-fertility countries are shown in table II.3 for the market economies of Europe and in table II.4 for the countries with economies in transition. They were derived from the experience of low-fertility countries (United Nations, 2006) by fitting a simple Beta distribution to the age-specific fertility patterns typical of market-economy countries (e.g., the Netherlands) and of countries with economies in transition (e.g., Slovenia). By varying the parameters of the Beta distribution in a manner similar to that implied by past trends, a set of model age-specific fertility patterns was generated with different mean ages of childbearing. The model age patterns of fertility developed for Europe were also used for several of the low-fertility countries outside of Europe. In certain other low-fertility countries, the proportionate age pattern of fertility was assumed to remain constant over the projection period.

TABLE II.3. MODEL AGE PATTERNS OF FERTILITY USED FOR THE MARKET ECONOMY COUNTRIES OF EUROPE

Model	*Percentage of total fertility by age group*							*Total*	*Mean age at childbirth*
	15-19	*20-24*	*25-29*	*30-34*	*35-39*	*40-45*	*45-49*		
1	2.2	22.9	43.2	26.2	5.2	0.2	0.0	100	28.0
2	1.5	17.5	40.4	31.4	8.7	0.6	0.0	100	29.0
3	1.0	13.2	36.3	35.3	13.0	1.3	0.0	100	30.0
4	0.6	9.8	31.6	37.6	17.9	2.5	0.0	100	31.0
5	0.4	7.2	26.7	38.1	23.0	4.5	0.1	100	32.0

TABLE II.4. MODEL AGE PATTERNS OF FERTILITY USED FOR THE COUNTRIES WITH ECONOMIES IN TRANSITION

Model	*Percentage of total fertility by age group*							*Total*	*Mean age at childbirth*
	15-19	*20-24*	*25-29*	*30-34*	*30-39*	*40-45*	*45-49*		
1	7.9	35.3	38.4	15.9	2.4	0.1	0.0	100	26.0
2	5.6	29.5	39.3	21.0	4.4	0.2	0.0	100	27.0
3	4.0	24.1	38.4	25.6	7.3	0.6	0.0	100	28.0
4	2.8	19.4	36.2	29.5	10.8	1.3	0.0	100	29.0
5	2.0	15.4	33.1	32.1	14.8	2.5	0.1	100	30.0

2. High-fertility assumption

Under the high variant, fertility is projected to remain 0.5 children above the fertility in the medium variant over most of the projection period. By 2020-2025, fertility in the high variant is therefore half a child higher than that of the medium variant. That is, countries reaching a total fertility rate of 2.1 children per woman in the medium variant have a total fertility rate of 2.6 children per woman in the high variant.

3. Low-fertility assumption

Under the low variant, fertility is projected to remain 0.5 children below the fertility in the medium variant over most of the projection period. By 2020-2025, fertility in the low variant is therefore half a child lower than that of the medium variant. That is, countries reaching a total fertility rate of 2.1 children per woman in the medium variant have a total fertility rate of 1.6 children per woman in the low variant.

4. Constant-fertility assumption

As the name implies, under the constant-fertility variant, fertility in all countries remains constant at the level estimated for 2005-2010.

5. Instant-replacement assumption

For each country, fertility is set to the level necessary to ensure a net reproduction rate of 1 starting in 2010-2015. Fertility varies over the remainder of the projection period in such a way that the net reproduction rate always remains equal to one thus ensuring, over the long-run, the replacement of the population.

B. Mortality assumptions: Increasing life expectancy for most countries

1. Normal-mortality assumption

Assumptions are made in terms of life expectancy at birth by sex. As in previous *Revisions*, life expectancy was generally assumed to rise over the projection period for most countries. In contrast with the assumptions made about future fertility trends, only one variant of future mortality trends (median path) was used for each country for the standard projection variants (e.g., high, medium and low fertility variants).

The *2012 Revision* of the *World Population Prospects* used new probabilistic methods for projecting life expectancy at birth building on the same approach used in earlier revisions (i.e., modelling of the pace of change of life expectancy at a given level of mortality), but has incorporated recent methodological advances developed in collaboration with the Probabilistic Projections Group of the Center for Statistics and the Social Sciences (CSSS) of the University of Washington (Raftery et al., 2012). The standard mortality projection assumption used for the *2012 Revision* introduced two new innovations: (1) future values of female life expectancy at birth are now based on a probabilistic projection model of life expectancy at birth (modelled as a random walk with drift where the drift is determined by a Bayesian Hierarchical Model (BHM)) (Raftery et al., 2013), and (2) future male life expectancies at birth take into account the correlation between female and male life expectancies and the empirical regularity that life expectancy is typically higher for females than for males. In the *2012 Revision*, the gap between female and male life expectancies is a function of female life expectancy and modelled using a new autoregressive model with an error term that has a Student's t-distribution to account for outliers, often corresponding to periods of conflicts, disasters or crises (Raftery, Lalic and Gerland, 2012). The method is based on empirical mortality trends estimated for the *2012*

Revision for all countries[19] of the world (excluding those having ever experienced 2 per cent or more adult HIV prevalence) for the period 1950 to 2010 (or up to 2010-2015 for Afghanistan and Syria).

a. General approach

The often dramatic decline of mortality was a driving force behind the profound changes to population trends observed during the past two centuries. While first limited to a small number of countries in the world, the decline of mortality and rise in life expectancy has become a global phenomenon.

In past revisions of the *World Population Prospects,* for countries where mortality was assumed to follow a declining trend, the pace of improvement of life expectancy at birth was set deterministically for each sex and country based on one of five models of gains in life expectancy estimated from a broad empirical basis of increasing life expectancy during the period 1950 to 2005, covering life expectancies between 50 and about 85 years (United Nations, 2010). The models represented the average experience of this historical period grouped according to the 90th percentile (very fast, modelled on Japan), the 75th percentile (fast model) the arithmetic mean (medium model), the lowest 25th percentile (slow model), and the lowest 10th percentile (the very slow model). These models produced smaller gains in life expectancy the higher the life expectancy already reached. The selection of a model for each country was based on recent trends in life expectancy by sex. For countries highly affected by the HIV/AIDS epidemic, the model incorporating a slow pace of mortality decline was generally used to project a certain slowdown in the reduction of general mortality risks not related to HIV/AIDS.

The new probabilistic method used in the *2012 Revision* for projecting life expectancy at birth was done in two separate steps:

The first step focuses on progress made in female life expectancy at birth, and models the sequence of change from high to low mortality (Raftery et al., 2013). The transition from high to low mortality can be decomposed into two processes, each of which can be approximated by a logistic function. The first process consists of initial slow growth in life expectancy and the diffusion of progress against mortality (e.g., small mortality improvements at low levels of life expectancy associated with diffusion of hygiene and improved nutrition), followed by a period of accelerated improvements, especially for infants and children (e.g., larger gains associated with greater social and economic development, mass immunization, etc.). The second process begins once the easiest gains have been achieved, mainly against infectious diseases, and produces continuing gains against non-communicable diseases. These improvements occur at a slower pace because of the ever-greater challenges in preventing premature deaths at older ages (Fogel, 2004; Riley, 2001).

[19] Only countries or areas with 90,000 persons or more in 2013 are considered.

For all countries undergoing mortality transition, the pace of improvement in life expectancy at birth is decomposed into a systematic decline and random distortion terms. The pace of the systematic gains in life expectancy at birth is modelled as a function of its level, based on the current UN methodology using a double-logistic improvement function. The parameters of the double-logistic function are estimated using a Bayesian Hierarchical Model (BHM), which results in country-specific distributions for the parameters of the gains in life expectancy. These distributions are informed by historical trends within each country (including pre-1950 data for 29 countries with good vital registration[20]), as well as the variability in historical mortality trends of all countries. For the *2012 Revision*, historical series on mortality have been included going back to 1870 in some cases. This increases the sample of mortality experience and enables the model to take into account the total historical experience which is useful when attempting to say something meaningful about uncertainty. The model is hierarchical because in addition to the information available for a particular country, a second-level of information derived from the world's experience is used to inform the statistical distributions of the parameters of the double-logistic.

Under these conditions, the pace of improvement and the asymptotic limit in future gains in female life expectancy vary for each projected trajectory, but ultimately is informed and constrained by the finding that the rate of increase of maximum female life expectancy over the past 150 years has been highly linear (i.e., about 2.4 years per decade (Oeppen and Vaupel, 2002; Vaupel and Kistowski, 2005), albeit at a slightly lower pace after the vanguard countries started to exceed 75 years of female life expectancy at birth in the 1960s (about 2.26 years of gains per decade (Vallin and Mesle, 2009). By assuming that the asymptotic average rate of increase in life expectancy is nonnegative, life expectancy is assumed to continually increase (on average), and no limit is imposed on life expectancy in the foreseeable future. The increase in maximum female life span among countries with the highest life expectancy and the most reliable data on very old age has provided further guidance on future rate of progress, which has also been increasingly linearly at least since the 1970s (about 1.25 years per decade for countries like Sweden and Norway (Wilmoth, Deegan, Lundstrom and Horiuchi, 2000; Wilmoth and Ouellette, 2012; Wilmoth and Robine, 2003)), and was used to inform the asymptotic average rate of increase in female life expectancy used in the *2012 Revision*[21].

The second step focuses on male mortality, and models the gap between female and male life expectancy at birth. Probabilistic projections of female life expectancy at birth (obtained through step one) were used in conjunction with stochastic projections of the gender gap to produce probabilistic projections of male life expectancy at birth, taking into account the correlation between female and male life expectancies, and the existence of outliers during periods of crises or conflict (Raftery, Lalic and Gerland, 2012).

The gap in life expectancy at birth between females and males is modelled using an autoregressive model with female life expectancy used as a covariate. A large body of literature exists on biological, behavioural and socioeconomic factors underlying the gap in life expectancy between females and males (Oksuzyan et al., 2008; Rogers et al., 2010; Trovato and Heyen, 2006; Trovato and Lalu, 1996, 1998), and the recent narrowing of the gap in high-income countries (Glei and Horiuchi, 2007; Meslé, 2004; Oksuzyan et al., 2008; Pampel, 2005). The pattern of decline in the gap in life expectancy observed for high-income countries, and for some emerging economies is assumed to apply in the future to other countries as well as through the diffusion of effective public health and

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[20] Consolidated historical dataset (e0F_supplemental.txt and e0M_supplemental.txt for female and male respectively) for 29 countries or areas covering the period 1750-1950 (including 20 countries with data since at least 1900) as part of the R Package used for this analysis (bayesLife and wpp2012), and based on a series for 5-year periods from the following sources: (1) University of California at Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). (2012). *Human Mortality Database* Available at www.mortality.org or www.humanmortality.de. Data downloaded on 9 Jan. 2012; (2) University of California at Berkeley (USA), Max Planck Institute for Demographic Research (Germany), and Institut National d'Etudes Demographiques (France). *Human Life-Table Database (2011)*. Available at www.lifetable.de. Data downloaded on 29 Dec. 2011; (3) Statistics Finland (2006). *Statistical Yearbook of Finland 2006*; (4) Hungarian Central Statistical Office (2006). *Hungary Demographic Yearbook 2005*; (5) Japan Ministry of Internal Affairs and Communication (2012). *Historical Statistics of Japan*. Available at: www.stat.go.jp/english/data/chouki/; (6) Andreev E.M. et al. (1998). *Demographic History of Russia 1927-1959*. Informatika, Moscow.

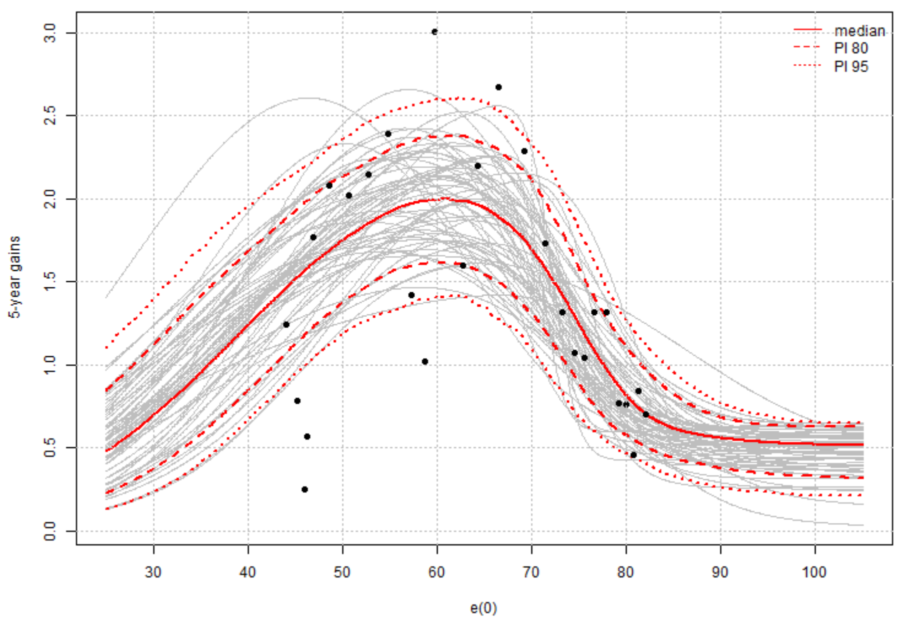
[21] Following Raftery et al. (2013) formal notation, to set the posterior median to an annual gain of 0.125 year (or 5-year gain of 0.625 in this context), the upper bound value of 0.653 was used for the world prior (z) and country-specific prior (z^c) in the estimation of the double-logistic parameters.

safety measures and medical interventions (Bongaarts, 2009; Vallin, 2006). Practically this means that based on past experience across the world, the future gender gap is expected to widen when life expectancy low, but once female life expectancy reaches about 75 years, the gap stops widening and starts narrowing up to about 83 years (as observed in high income countries, and some emerging economies). Once projected future female life expectancy reaches or exceeds the highest observed levels of female life expectancy (about 83 years for the *2012 Revision*), the gap is modelled as a random walk with normally distributed changes and no drift because little information on the determinants of changes in the gap exist at these high ages and beyond.

To produce joint probabilistic projections of female and male life expectancy, a large number of future trajectories for the gap in life expectancy have been simulated. For each simulated value of the gap, the simulated male life expectancy projection is obtained by subtracting it from a simulated value of female life expectancy projection.

To construct projections of female life expectancy at birth for all countries without generalized HIV/AIDS epidemic, the Bayesian Hierarchical Model was used to generate 1,450,000[22] double-logistic curves for each country (see example in figure II.12), representing the uncertainty in the double-logistic gain function (graphs of this double-logistic curve are available online[23]). The sample of double-logistic curves is then used to calculate over 100,000 life expectancy projections for each country. For each trajectory, at any given time, the double-logistic function gives the expected improvement in life expectancy based on its current level. A distortion term was also added to the expected gain in life expectancy. (This distortion term represents the deviations of life expectancy increments from the double-logistic curve, as observed in past experiences).

Figure II.12. Female gains in life expectancy at birth and projection intervals of double-logistic curves for Canada (systematic decline part)



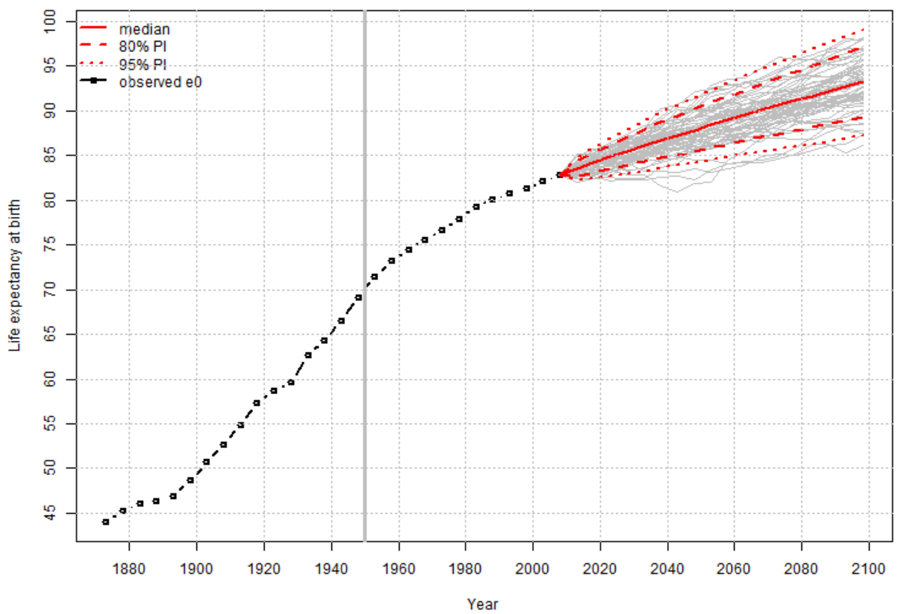
NOTE: The observed five-year gains by level of life expectancy at birth (e(0)) are shown by black dots. For clarity, only 60 trajectories from 1,450,000 are displayed. The median projection is the solid bold red line, and the 80% and 95% projection intervals are displayed as dashed and dotted red lines respectively. In addition to estimates of female life expectancy at birth for the period 1950-2010 (based on the *2012 Revision*), historical data for pre-1950 periods are included in the analysis upon availability. For Canada, 5-year series for the period 1870-1950 only are used.

[22] Actually ten simulations are run in parallel with 155,000 iterations performed for each simulation, and the first 10,000 are discarded.

[23] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of female gains in life expectancy at birth curves (based on Double-Logistic function) from the Bayesian Hierarchical Model (BHM): median, 80 per cent and 95 per cent projection intervals: http://esa.un.org/unpd/wpp/LifeExpectancy_figures/interactive-figures_DL-functions.htm.

For each country, the end result is over 100,000 projected trajectories of female life expectancy at birth (based on a systematic sampling of 1/14 of the 1,450,000 simulated trajectories of change in fertility). The median of these 100,000 trajectories is used as the standard mortality projection in the *World Population Prospects*. To evaluate future trends in female life expectancy at birth, 80 per cent and 95 per cent projection intervals have also been calculated (see figure II.13 for Canada, additional tables[24] and graphs[25] are available online for all countries).

Figure II.13. Probabilistic trajectories of projected female life expectancy at birth (2010-2100) for Canada



NOTE: For clarity, only 60 trajectories from 100,000 are displayed. The median projection is the solid bold red line, and the 80 per cent and 95 per cent projection intervals are displayed as dashed and dotted red lines respectively. In addition to estimates of female life expectancy at birth for the period 1950-2010 (based on the *2012 Revision*), historical data (i.e, before 1950 as marked by vertical grey line) are included in the analysis upon availability. For Canada, 5-year series for the period 1870-1950 are used.

Overall, the approach works well for most countries that have experienced normal mortality improvements since the 1950s. But two small sets of countries stood out either because of (a) much faster or (b) much slower improvements than typically experienced by other countries. Countries that have experienced much faster gains in life expectancy at birth since the 1950s are often countries that still have relatively low life expectancy at birth even though they may have made substantially faster progress than those historically observed in other countries (e.g., Afghanistan, Bangladesh, Bhutan, Bolivia, Cambodia, Cape Verde, Ecuador, Eritrea, Lao PDR, Lebanon, Madagascar, Maldives, Nepal, Nicaragua, Niger, Oman, Peru, Turkey, and Western Sahara). The second set of countries includes economies in transition (e.g., countries in Eastern Europe and the former Soviet Union) that have experienced long period of stagnating or even increasing mortality. In both cases, the four parameters of the double logistic function responsible for future gains beyond around 60 years of life expectancy have been informed by the experience of the leading countries in their respective region[26]. In the first case, this approach was used to temper over-optimistic gains for some countries in the distant future that would lead to implausible crossovers in long-term projections (i.e., countries that are lagging

[24] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online tables of probabilistic projections of female life expectancy at birth: median, 80% and 95% projection intervals http://esa.un.org/unpd/wpp/LifeExpectancy_figures/data/wpp2012_mort_ppp_life_expectancy_0_female.xls.

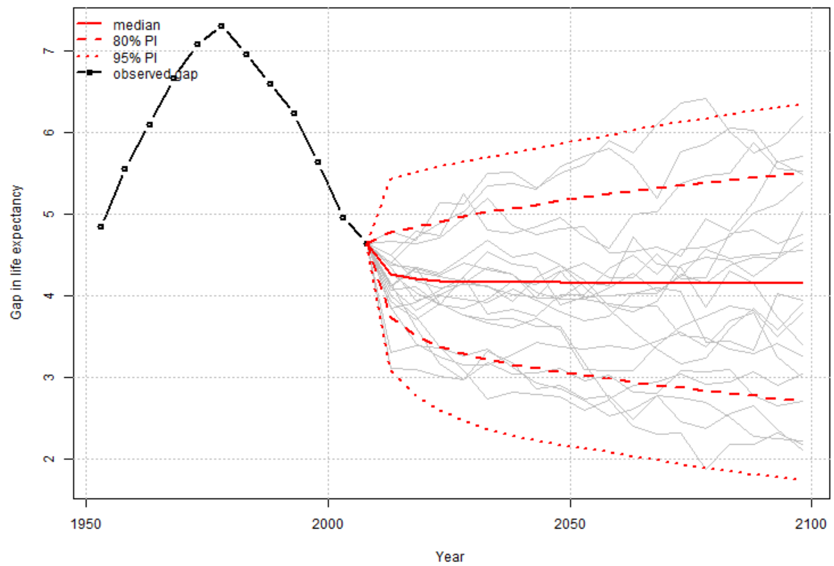
[25] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of probabilistic projections of female life expectancy at birth: median, 80% and 95% projection intervals: http://esa.un.org/unpd/wpp/LifeExpectancy_figures/interactive-figures_e0-trajectories-Female.htm.

[26] Following Raftery et al. (2013), formal notation, country-specific priors were specified for the first set of countries for the upper bound of the Δ_{c3}, Δ_{c4}, k^c and z^c double-logistic parameters while for the second set of countries lower bound were used for these parameters. In general, the upper quartile of the distribution of these parameters for the best performers in each region was used to inform other countries.

today becoming leaders by 2100). In the second case, this approach was used to provide further guidance on the trajectory of long term potential gains for countries that have experienced mortality stagnation or worsening (i.e., it is assumed that, in the long run, these countries will gradually catch up with the more advanced countries in their region).

To construct projections of male life expectancy at birth, the gender gap autoregressive model was then used in conjunction with probabilistic projections of female life expectancy at birth to generate 100,000 trajectories for each country (see example in figure II.14), representing the uncertainty in the future gap between female and male life expectancy projections (graphs of the gender gap trajectories are available online[27]).

Figure II.14. Gap in female-male life expectancy at birth and projection intervals for Canada

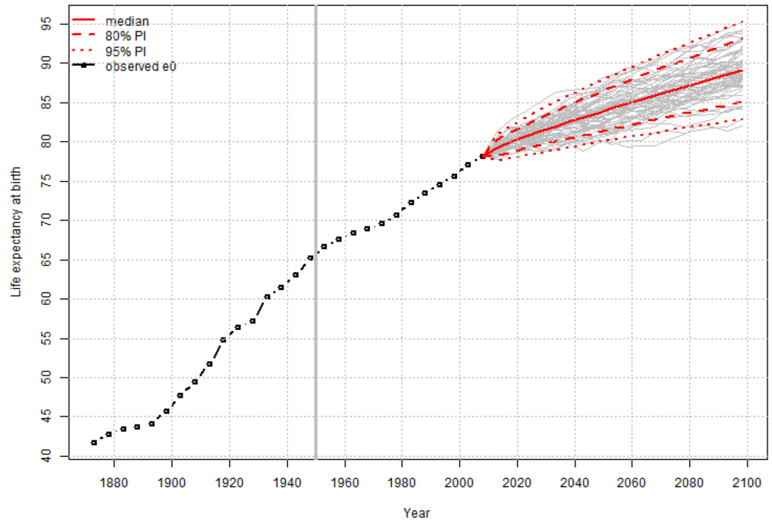


NOTE: The observed gap between female and male life expectancy at birth are shown by black dots and solid line. For clarity, only 60 trajectories from 100,000 are displayed. The median projection is the solid bold red line, and the 80 per cent and 95 per cent projection intervals are displayed as dashed and dotted red lines respectively.

The sample of gender gap trajectories was then used to calculate over 100,000 male life expectancy projections for each country. The median of these projections was used as the standard mortality projection in the *World Population Prospects*. To evaluate future trends in male life expectancy at birth, 80 per cent and 95 per cent projection intervals were also calculated (see figure II.15 for Canada, additional tables[28] and graphs[29] are available online for all countries).

[27] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of female-male gap in life expectancy at birth: median, 80% and 95% projection intervals: http://esa.un.org/unpd/wpp/LifeExpectancy_figures/interactive-figures_e0-MFGap.htm.
[28] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online tables of probabilistic projections of male life expectancy at birth: median, 80% and 95% projection intervals http://esa.un.org/unpd/wpp/LifeExpectancy_figures/data/wpp2012_mort_ppp_life_expectancy_0_male.xls.
[29] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of probabilistic projections of female life expectancy at birth: median, 80% and 95% projection intervals: http://esa.un.org/unpd/wpp/LifeExpectancy_figures/interactive-figures_e0-trajectories-Male.htm.

Figure II.15. Probabilistic trajectories of projected male life expectancy at birth (2010-2100) for Canada



NOTE: For clarity, only 60 trajectories from 100,000 are displayed. The median projection is the solid bold red line, and the 80 per cent and 95 per cent projection intervals are displayed as dashed and dotted red lines respectively. In addition to estimates of life expectancy at birth for the period 1950-2010 (based on the *2012 Revision*), historical data (i.e, before 1950 as marked by vertical grey line) were included in the analysis when available. For Canada, 5-year series for the period 1870-1950 were used.

The relationship between probabilistic projections of male and female life expectancies at birth for selected projection periods (e.g., 2010–2015, 2050–2055 and 2095–2100) can be summarized through scatter plots showing a subsample of 500 probabilistic trajectories of life expectancy at birth for both male and female (see example in figure II.16). The 80 per cent and 95 per cent projection intervals are displayed as ellipses respectively. The relationship if both male and female life expectancies are equal is displayed with a diagonal line. Graphs of the joint distributions of life expectancy by sex are available online.[30]

As with the new modelling approach to fertility, the results of this new approach for life expectancy produces country-specific projections of life expectancy at birth that are fully reproducible and take into account past empirical trends. Extensive documentation for all countries and areas has been posted online[31], and further details about the methodology are available from Raftery et al. (Raftery et al., 2013; Raftery, Lalic and Gerland, 2012). In addition, an open-source and portable software implementation of the new UN approach to project life expectancy, based on the R statistical language, developed by Sevcikova et al. is available as a fully documented R package (bayesLife[32]) through the public R CRAN archive together with a user-friendly Graphical User Interface (bayesDem[33]), and the full dataset used for the *2012 Revision*[34]. Version 2.0-0 of the bayesLife package was used to compute the final set of projections used for the *2012 Revision* of the *World Population Prospects*[35].

[30] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of Comparison between probabilistic projections of male and female life expectancies at birth for selected projection periods: 80% and 95% prediction intervals:
http://esa.un.org/unpd/wpp/LifeExpectancy_figures/interactive-figures_e0-MFCompare.htm.

[31] United Nations, Department of Economic and Social Affairs, Population Division (2013). *World Population Prospects: The 2012 Revision*. New York. Online plots of probabilistic projections of female life expectancy at birth: median, 80% and 95% projection intervals:
http://esa.un.org/unpd/wpp/LifeExpectancy_figures/interactive-figures_e0-trajectories-Female.htm.

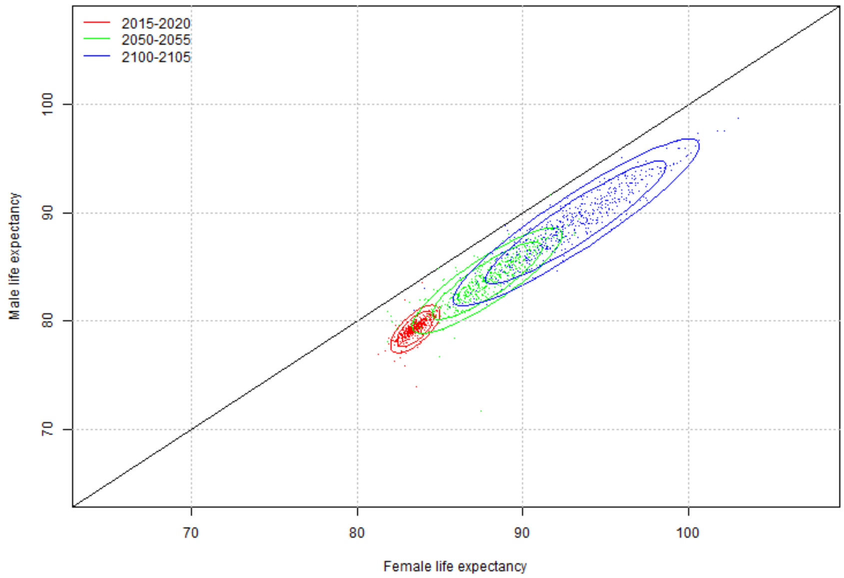
[32] Sevcikova, H., A. Raftery and J. Chunn (2013). bayesLife: Bayesian Projection of Life Expectancy. *R Package and documentation*: http://cran.r-project.org/web/packages/bayesLife/index.html.

[33] Sevcikova H. (2013). bayesDem: Graphical User Interface for bayesTFR and bayesLife. *R Package and documentation*:
http://cran.r-project.org/web/packages/bayesDem/index.html.

[34] Sevcikova H. et al. (2013). wpp2012: World Population Prospects 2012. *R Package and documentation*:
http://cran.r-project.org/web/packages/wpp2012/.

[35] The estimates of the double logistic parameters are based on ten parallel chains of 155,000 iterations discarding the first 10,000 of each chain to yield a total of 1,450,000 samples of all model parameters. For each country, 100,000 trajectories for each sex were projected, and

Figure II.16. Comparison of probabilistic projections of female and male life expectancies at birth for selected periods for Canada



NOTE: For clarity, only 500 projected trajectories from 100,000 are displayed for each sex. The 80 per cent and 95 per cent projection intervals are displayed as ellipses respectively. The relationship if both male and female life expectancies are equal is displayed with a diagonal line.

b. Projection of the age pattern of mortality

Once the path of future expectation of life was determined, mortality rates by five-year age group and sex that are consistent with the expectation of life at birth for each quinquennium were calculated. For countries with recent empirical information on the age patterns of mortality, mortality rates for the projection period were obtained by extrapolating the most recent set of mortality rates by the rates of change from: (a) country-specific historical trends using an extended Lee-Carter approach (Li, Lee, and Gerland, 2013)[36], or (b) typical age-specific patterns of mortality improvement by level of mortality estimated from individual country experiences included in the Human Mortality Database (Andreev, Gu, and Gerland, 2013)[37], or (c) from extended model life tables (Li and Gerland, 2011). In both instances, additional constrains were sometimes used at younger and/or older ages to insure greater consistency in sex differentials, especially at very high levels of projected life expectancies.

In other words, under such procedures, the empirical or estimated age pattern of mortality is transformed as life expectancy changes over time. For countries lacking recent or reliable information on age patterns of mortality, mortality rates were directly obtained from an underlying model life table. A choice could be made among nine model life table systems, four proposed by Coale and Demeny (1966); Coale, Demeny and Vaughn (1983); and Coale and Guo (1989), and five model systems for developing countries produced by the United Nations (1982). These nine model life tables have been updated and extended by the Population Division in order to cover the whole age range up 100 years, and a range of life expectancies from 20 to 100.0 years[38]. It must be noted that the last

used to derive the median and other projection intervals. Total computation time was about 2 days on a 64-bit Windows 7 workstation with multicore processors. The seed of the random number generator for the Markov Chain Monte Carlo estimation used was: 20130523.

[36] In this case, the extended Lee-Carter approach is constrained to the projected median UN life expectancy at birth by selecting appropriate increases in the level parameter (k_t) for each of the projection periods with the age pattern (a_x) based on the most recent period or the average 1950-2010 period, and the age pattern of mortality improvement (b_x) gradually changes by level of mortality to reflect the fact that mortality decline is decelerating at younger ages and accelerating at old ages.

[37] Note: available demographic data have permitted reliable estimation of the patterns of mortality improvement only up to 75-80 years of e0 for males, and 80-85 years for females. For extrapolating patterns of mortality improvement into higher levels of life expectancy at birth, smoothed linear trends were extrapolated for levels of life expectancy at birth up to 105-110 years of age.

[38] United Nations Population Division (2010). *World population prospects: the 2010 revision—WPP 2010 extended model life tables*. New York: United Nations. Available online at: http://esa.un.org/unpd/wpp/Model-Life-Tables/download-page.html.

available entry in the revised system of model life tables of 100.0 years of life expectancy, for both males and females, are not meant to represent a ceiling for human longevity.

The general approach to the projection of mortality just described is not appropriate for countries significantly affected by the HIV/AIDS epidemic. A detailed description of assumptions made and models used to estimate and project the demographic impact of HIV/AIDS is given in the next section.

2. The impact of HIV/AIDS on mortality

The *2012 Revision* has incorporated the demographic impact of the HIV/AIDS epidemic for 39 countries where HIV prevalence among persons aged 15 to 49 was ever equal to or greater than two per cent between 1980 and 2011. Of 39 countries examined, 32 countries were in Africa, 1 was in Asia and 6 were in Latin America and the Caribbean (table II.5). For those countries, especially those having experienced prevalence rates of five per cent or more, a different approach for the estimation and projection of mortality had to be used.

There are a number of reasons why the HIV/AIDS epidemic requires the development of a separate explicit modelling process. Unlike other infectious diseases, HIV/AIDS has a very long incubation period in which an infected person is mostly symptom-free but infectious. Also unlike many other infectious diseases, individuals do not develop immunity, but, in the absence of treatment, almost always die as a consequence of their compromised immune system. Another reason for an explicit modelling of the HIV/AIDS is the avalanche-like process of the infection spreading through a population and the particular age pattern exhibited by HIV/AIDS. The additional deaths due to HIV/AIDS, predominantly adults in their reproductive age, are consequently distorting the usual U-shaped age-specific age profile of mortality, a feature which cannot be found in the model life tables that are available to demographers (Heuveline, 2003). Thus the particular dynamic of this disease and the severity of its outcome require an explicit modelling of the epidemic.

As a consequence, instead of an overall mortality process that can be captured by standard age patterns of mortality and smooth trends of changing life expectancy, for countries highly affected by HIV/AIDS, two separate mortality processes must be modelled: the mortality due to the HIV/AIDS epidemic itself and the mortality that prevails among the non-infected population. The latter is often called the level of “background mortality”.

In countries with lower HIV prevalence rates (i.e., under 5-7 per cent), when sufficient empirical evidence on adult mortality was available, explicit modelling of adult mortality by sex was used in conjunction with estimates of under-five mortality to derive mortality rates by age and sex (see online Data Sources[39] for country-specific details).

In countries most highly affected by the HIV/AIDS epidemic, mortality was projected by modelling explicitly the course of the epidemic and projecting the yearly incidence of HIV infection. The model[40] developed by the UNAIDS Reference Group on Estimates, Modelling and Projections (Stanecki, Garnett, and Ghys, 2012; Stover, Brown, and Marston, 2012), and all epidemiological parameters (including treatment data) used by UNAIDS to prepare the 2011 set of UNAIDS/WHO estimates[41] for the 2012 Global Report (UNAIDS, 2012) were used to derive the mortality impact due to HIV/AIDS.

[39] Data sources and related meta-information for the *2012 Revision* of the *World Population Prospects* are available for each country from the following web page: http://esa.un.org/unpd/wpp/Excel-Data/data-sources.htm and in an Excel file (WPP2012_F02_METAINFO.XLS).
[40] A special release of *Spectrum* (UNPOP100, 4 April 2013). specially extended to handle higher life expectancy projections up to age 100 was used for the *2012 revision*. Public versions of *Spectrum* are available at: http://www.futuresinstitute.org/pages/resources.aspx.
[41] The only exception was a revised age pattern of incidence by sex for generalized epidemic provided by UNAIDS in Nov. 2012 (mean age of new infections equal to 28.1 for females and 32.5 for males).

Table II.5. Adult 15-49 HIV prevalence rate in the countries most affected by the HIV/AIDS epidemic between 1980 and 2011

Region/Country	*Adult HIV prevalence rate (%) in 2011*	*Maximum HIV rate (%) between 1980 and 2011*	*Year maximum reached*	*Region/Country*	*Adult HIV prevalence rate (%) in 2011*	*Maximum HIV rate (%) between 1980 and 2011*	*Year maximum reached*
Africa				Africa			
Angola	2.1	2.1	2011	Namibia	13.4	15.9	2002
Benin	1.2	3.8	1987	Nigeria	3.7	3.8	2002
Botswana	23.4	27.0	2001	Rwanda	2.9	5.8	1989
Burkina Faso	1.1	3.8	1989	South Africa	17.3	17.3	2011
Burundi	1.3	5.1	1996	South Sudan	3.1	3.1	2008
Cameroon	4.6	5.2	2003	Swaziland	26.0	26.0	2011
Central African Rep.	4.6	9.5	1995	Togo	3.4	4.2	2003
Chad	3.1	3.7	1999	Uganda	7.2	13.6	1989
Congo	3.3	5.2	1992	UR of Tanzania	5.8	8.4	1996
Cote d'Ivoire	3.0	7.3	1996	Zambia	12.5	14.9	1993
Djibouti	1.4	2.8	1999	Zimbabwe	14.8	27.3	1998
Equatorial Guinea	4.7	4.7	2011	Asia			
Ethiopia	1.4	3.7	1999	Thailand	1.2	2.1	1995
Gabon	5.0	5.5	2004	Latin America and the Caribbean			
Ghana	1.5	2.2	2000	Bahamas	2.8	4.0	1993
Guinea-Bissau	2.5	2.5	2011	Belize	2.3	2.4	2004
Kenya	6.2	9.8	1997	Haiti	1.8	3.3	1993
Lesotho	23.3	23.5	2001	Honduras	0.6	2.8	1995
Liberia	1.0	2.5	2000	Jamaica	1.8	2.5	1998
Malawi	10.0	13.8	2001	Suriname	1.0	3.3	1996
Mozambique	11.3	11.3	2007				

Source: 2011 set of UNAIDS/WHO estimates (unpublished tabulations) and UNAIDS. (2012). AIDS Info Database. Retrieved 30 November 2012, from Joint United Nations Programme on HIV/AIDS (UNAIDS) http://www.aidsinfoonline.org/

The projection assumptions used in the *2012 Revision* assumed that the HIV incidence rate observed though 2011 would decline by 2100 to about 1/10 its 2011 value following an exponential decay function. The sex ratio of HIV incidence (female to male incidence for age 15-49) was assumed to follow a linear trend from its 2011 value to reach 1.1 in 2050 and to remain constant thereafter. Both for children and adults, the proportion of the HIV-positive population receiving treatment in each country used estimates prepared by the World Health Organization and UNAIDS, and the coverage was projected to reach 85 per cent in 2050 if it was currently below 85 per cent or stay constant if it was above it. Coverage of interventions to prevent mother-to-child transmission of HIV was assumed to remain constant until 2100 at the level reached in each of the affected countries in 2011.

3. Constant-mortality assumption

Under this assumption, mortality over the projection period is maintained constant for each country at the level estimated for 2005-2010.

C. International migration assumptions

International migration is the component of population change most difficult to project. This is primarily due to the fact that data on past trends are often sparse or incomplete, and because the movement of people across international borders, which is often a response to rapidly changing economic, social, political and environmental factors, is a very volatile process. Not only has international migration shown drastic changes in absolute numbers, but the direction of the flows has changed as well so that some countries that historically have been primarily countries of origin have become countries of destination and vice versa. Therefore, formulating assumptions about future trends in international migration is extremely difficult. Where migration flows have historically been small and have had little net impact on the demography of a country, then adopting the assumption that migration will remain constant throughout most of the projection period is usually acceptable. In situations where migration flows are the dominant demographic force of change, more attention is needed.

When a person moves from one country to another, that person is an emigrant when leaving the country of origin and becomes an immigrant when entering the country of destination. Because immigration and emigration flows affect countries differently, international migration is ideally studied as the flow of people moving between countries. In practice, data on international migration flows only exist for a small number of countries. Therefore, international migration in this *Revision*, as in previous ones, has been incorporated as net migration. Net migration - the difference between the number of immigrants and the number of emigrants for a particular country and period of time - shows the net effect of international migration on the respective population. It does not provide an indication about the number of immigrants and emigrants involved. In an extreme case, immigration and emigration for a country could be significant, but if the number of immigrants was equal to the number of emigrants, net migration would amount to zero.

In preparing assumptions about future trends in international migration, several pieces of information were taken into account: (*1*) information on net international migration or its components (immigration and emigration) as recorded by countries; (*2*) data on labour migration flows; (*3*) estimates of undocumented or irregular migration; (*4*) and data on refugee movements in recent periods.

The basic approach for formulating future net international migration assumptions is straight-forward. For any given country, a distinction was made between international migration flows and the movement of refugees. For international migration, it was assumed that recent levels, if stable, would continue throughout the projection period. Government's views on international migration as well as estimates of undocumented and irregular migration flows affecting a country were also considered (see, for example United Nations, 2003). Regarding the movements of refugees, it was assumed in general that refuges return to their country of origin within one or two projection periods, i.e. 5 to 10 years. If a country experienced both international migration and refugee movements, the two processes were added in order to capture the overall net migration during a particular period in the future.

Usually, migration assumptions are expressed in terms of the net number of international migrants. The distribution of migrants by sex was established on the basis of what was known about the participation of men and women in different types of flows for any given country (*i.e.*, labour migration, family reunification, etc.). Given the lack of suitable information on the age distribution of migrant flows, models were generally used to distribute the overall net number of male and female migrants by age group according to the dominant type of migration flow assumed (for example, labour migration or family migration). The age and sex profiles of the net migration flows were then used as input for the cohort-component projection model (Castro and Rogers, 1983; United Nations, 1989, pp. 65-70). In the rare instances when the age and sex distribution of international migrants was known, those distributions were used to determine which model was most suitable or, in some cases, those data were used directly as input. The distribution of net migrants by age and sex was generally kept constant over the projection period. However, if a country was known to attract temporary labour migrants, an effort was made to model the return flow of those labour migrants accounting for aging of the migrants involved. The same idea was applied to refugee flows.

International migration has become a near universal phenomenon affecting virtually all countries of the world. For the few countries that were known neither to admit international migrants nor supply a sizeable number of migrants, net migration was assumed to be zero, or to become zero shortly after the start of the projection. However, the vast majority of countries were projected to experience non-zero net international migration during most of the projection period. Among these, almost twice as many were projected to be sending countries as receiving countries.

1. Normal migration assumption

Under the normal migration assumption, the future path of international migration is set on the basis of past international migration estimates and consideration of the policy stance of each country with regard to future international migration flows. Projected levels of net migration are generally kept constant over the next decades. After 2050, it is assumed that net migration would gradually decline and reach zero by 2100. This assumption is very unlikely to be realized but it proved impossible to predict the levels of immigration or emigration within each country of the world for such a far horizon. Sending countries of today may become receiving countries and vice versa.

2. Zero-migration assumption

Under this assumption, for each country, international migration is set to zero starting in 2010-2015.

D. EIGHT PROJECTION VARIANTS

The *2012 Revision* included eight different projection variants (see table II.6). Five of those variants differed only with respect to the level of fertility, that is, they shared the assumptions made with respect to mortality and international migration. The five fertility variants are: low, medium, high, constant-fertility and instant-replacement fertility. A comparison of the results from these five variants allows an assessment of the effects that different fertility assumptions have on other demographic parameters. The high, low, constant-fertility and instant-replacement variants differ from the medium variant only in the projected level of total fertility. In the high variant, total fertility is projected to reach a fertility level that is 0.5 children above the total fertility in the medium variant. In the low variant, total fertility is projected to remain 0.5 children below the total fertility in the medium variant. In the constant-fertility variant, total fertility remains constant at the level estimated for 2005-2010. In the instant replacement variant, fertility for each country is set to the level necessary to ensure a net reproduction rate of 1.0 starting in 2010-2015. Fertility varies slightly over the projection period in such a way that the net reproduction rate always remains equal to one, thus ensuring the replacement of the population over the long run.

In addition to the five fertility variants, a constant-mortality variant, a zero-migration variant and a “no change” variant (i.e., both fertility and mortality are kept constant) have been prepared. The constant-mortality variant and the zero-migration variant both used the same fertility assumption (medium fertility). Furthermore, the constant-mortality variant has the same international migration assumption as the medium variant. Consequently, the results of the constant-mortality variant can be compared with those of the medium variant to assess the effect that changing mortality has on various population quantities. Similarly, the zero-migration variant differs from the medium variant only with respect to the underlying assumption regarding international migration. Therefore, the zero-migration variant allows an assessment of the effect that non-zero net migration has on various population quantities. Lastly, the “no change” variant has the same assumption about international migration as the medium variant but differs from the latter by having constant fertility and mortality. When compared to the medium variant, therefore, its results shed light on the effects that changing fertility and mortality have on the results obtained.

E. INTERPOLATION PROCEDURES

The cohort-component method used in the *2012 Revision* requires a uniform age format for the estimation of the size and structure of a population and the measurement of vital events. For the purpose of global population estimates and projections, most data are only available in five-year age groups. As a consequence, all results produced by the cohort-component method in the *2012 Revision* are also in five-year age groups and, for vital events, represent five-year periods. All vital rates are given as the average over the five-year period from mid-year (t) to mid-year (t+5) centred on 1 January year (t+3). For example, life expectancy at birth for 2000-2005 referred to the period from mid-2000 to mid-2005 (i.e., 2000.5 to 2005.5 in decimal dates), with 1 January 2003 as the mid-point

TABLE II.6. PROJECTION VARIANTS IN TERMS OF ASSUMPTIONS FOR FERTILITY, MORTALITY AND INTERNATIONAL MIGRATION

	Assumptions		
Projection variant	*Fertility*	*Mortality*	*International migration*
Low fertility	Low	Normal	Normal
Medium fertility	Medium	Normal	Normal
High fertility	High	Normal	Normal
Constant-fertility	Constant as of 2005-2010	Normal	Normal
Instant-replacement-fertility	Instant-replacement as of 2010-2015	Normal	Normal
Constant-mortality	Medium	Constant as of 2005-2010	Normal
No change	Constant as of 2005-2010	Constant as of 2005-2010	Normal
Zero-migration	Medium	Normal	Zero as of 2010-2015

(i.e., 2003.0 using a decimal date). Special interpolation routines were then used to produce estimates and projections for single calendar years and for single-year age groups. It must be noted, however, that interpolation procedures cannot recover the true series of events or the true composition of an aggregated age group.

a. Interpolation of populations by age and sex

The basis for the calculation of interpolated population figures by single year of age and for calendar years ending with either 0 or 5 were the estimated and projected quinquennial population figures by five-year age groups for each sex. In a first step, the quinquennial population figures were interpolated into annual population figures by applying Beers' ordinary formula (Swanson and Siegel, 2004, p. 728). The second step of this interpolation was to generate the population by single year of age for each year by applying Sprague's fifth-difference osculatory formula (Swanson and Siegel, 2004, p. 727) for subdivision of groups into fifths. This interpolation procedure generated a smooth interpolated series of figures while maintaining the original values. It should be noted that for ages above 80 and for age under five, the stability and reliability of the interpolation procedure was not always satisfactory.

In order to maintain consistency along cohort lines, a third step has been added. This third step is to interpolate linearly the populations by single year of age for each calendar year between those ending with 0 or 5, along the cohort survival line. For example, the populations at ages 1, 2, 3, and 4, in years 1951, 1952, 1953, and 1954 respectively, are linear interpolations between the population aged 0 in 1950 and the population aged 5 in 1955. The last such linear interpolation is carried out between age 94 at time t and age 99 at time t+5. Because of the last age group being open-ended, a linear interpolation is not possible beyond age 94. As a last step, the interpolation results are prorated such that the sum of all age groups between ages 0 and 99, before and after the linear interpolation, is the same.

b. Interpolation of vital events and summary statistics

For the interpolation of vital events, their rates and other measures into annualized times series, the modified Beers formula was used (Swanson and Siegel, 2004, p. 729). This formula combines interpolation with some smoothing. Beers modified methods were preferred over Beers "ordinary" formula as it avoided fluctuations at the beginning and the end of the series that were atypical for the variables concerned.

The time periods in the estimates and projections of this *Revision* were anchored to mid-year. Each observation or projection period starts at 1 July of a particular year and ends at mid-year five years later. Therefore, the annualized interpolated indicators refer to the period between the mid-year points of two consecutive calendar years. In order to provide annualized variables that refer to calendar years, an adjustment was made that simply assumed that the arithmetic average between two such periods would be a good representation of the calendar year based indicator.

F. TABULATIONS

Once the individual country projections are prepared, the results are aggregated into the world, regions, major areas, development groups and other aggregates. For a list of the aggregation units see the explanatory notes.

The aggregation of populations by age and sex and vital events by age and sex is performed by simply adding the variables according to lists that assign individual countries to the aggregates. For synthetic variables, like life expectancy, total fertility, median age or net reproduction rates, proper population weighted averages are calculated.

Finally, after estimates and projections for all countries are performed and aggregated, it is necessary to ensure that the sum of all international migration adds to zero at the global level. This is achieved by an iterative process in which individual country projections are re-visited and altered accordingly.

G. SUMMARY OF METHODOLOGICAL CHANGES INTRODUCED IN THE 2012 REVISION

The following summarizes the changes and adjustments that were made in the *2012 Revision* in relation to procedures followed in the *2010 Revision*.

- The *2012 Revision* used the same stochastic model for fertility projection that was used in the 2010 revision with only one modification: the AR1 model used for low-fertility countries was estimated using a Bayesian hierarchical model, and future long-term fertility levels were more data-driven and country-specific. The medium-fertility variant in the *2012 Revision* corresponds to the median of 60,000 projected country trajectories.
- The *2012 Revision* used two new stochastic models to project life expectancy at birth for all countries not significantly affected by the HIV/AIDS epidemic: the first model used a Bayesian hierarchical approach for modelling the rate of mortality improvement for women by level of life expectancy at birth. A second model was used to project the gender gap in life-expectancy conditionally on the level of female mortality. The medium-mortality variant in the *2012 Revision* corresponds to the median of 100,000 projected country trajectories by sex.
- The *2012 Revision* used new age-specific patterns of mortality improvement by level of mortality to project mortality patterns for countries with reliable recent mortality data by age and sex.
- In the *2012 Revision*, the impact of HIV/AIDS on mortality was modelled explicitly for 39 countries where HIV prevalence among persons aged 15 to 49 was at one time equal to, or greater than, two per cent between 1980 and 2011. The *2012 Revision* no longer includes the AIDS scenarios named No-AIDS, high-AIDS and AIDS-vaccine.

References

Alkema, L., Kantorova, V., Menozzi, C., and Biddlecom, A. (2013). National, regional, and global rates and trends in contraceptive prevalence and unmet need for family planning between 1990 and 2015: a systematic and comprehensive analysis. *Lancet, 381*(9878), 1642-1652. doi: 10.1016/S0140-6736(12)62204-1.

__________, and New, J. R. (2013). Global Estimation of Child Mortality Using a Bayesian B-spline Regression Model. *Arxiv.org*. http://arxiv.org/pdf/1309.1602.pdf

__________, Raftery, A., Gerland, P., Clark, S., Pelletier, F., Buettner, T., and Heilig, G. (2011). Probabilistic Projections of the Total Fertility Rate for All Countries. *Demography, 48*(3), 815-839. doi: 10.1007/s13524-011-0040-5.

__________, Raftery, A., Gerland, P., Clark, S. J., and Pelletier, F. (2012). Estimating Trends in the Total Fertility Rate with Uncertainty Using Imperfect Data: Examples from West Africa. *Demographic Research, 26*(15), 331-362. doi: 10.4054/DemRes.2012.26.15.

Andreev, K., Gu, D., and Gerland, P. (2013). *Patterns of Mortality Improvement by Level of Life Expectancy at Birth*. Paper presented at the Annual Meeting of the Population Association of America, New Orleans, LA. http://paa2013.princeton.edu/papers/132554

Basten, S. A. (2013). Re-Examining the Fertility Assumptions for Pacific Asia in the UN's 2010 World Population Prospects. In Department of Social Policy and Intervention (Ed.), *Barnett Papers in Social Research* (Vol. 2013, pp. 31). Oxford, UK: University of Oxford.

Bongaarts, J. (2009). Trends in senescent life expectancy. *Population Studies, 63*(3), 203-213. doi: 10.1080/00324720903165456.

__________, and Casterline, J. (2013). Fertility Transition: Is sub-Saharan Africa Different? *Population and Development Review, 38*, 153-168. doi: 10.1111/j.1728-4457.2013.00557.x.

__________, and Sobotka, T. (2012). A Demographic Explanation for the Recent Rise in European Fertility. *Population and Development Review, 38*(1), 83-120. doi: 10.1111/j.1728-4457.2012.00473.x.

Caltabiano, M., Castiglioni, M., and Rosina, A. (2009). Lowest-low fertility: Signs of a recovery in Italy. *Demographic Research, 21*(23), 681-718. doi: 10.4054/DemRes.2009.21.23.

Castro, L. J., and Rogers, A. (1983). What the age composition of migrants can tell us. *Popul Bull UN*(15), 63-79.

Coale, A. J., and Demeny, P. G. (1966). *Regional model life tables and stable populations*. Princeton, N.J.,: Princeton University Press.

__________, Demeny, P. G., and Vaughan, B. (1983). *Regional model life tables and stable populations* (2nd ed.). New York: Academic Press.

__________, and Guo, G. (1989). Revised Regional Model Life Tables at Very Low Levels of Mortality. *Population Index, 55*(4), 613-643.

Feeney, G. (1995). *The Analysis of Children Ever Born Data for Post-Reproductive Age Women*. Paper presented at the Notestein Seminar, Princeton, NJ. http://www.gfeeney.com/presentations/1995-ceb-for-praw/1995-ceb-for-praw.pdf

__________ (1996, November 1996). *A New Interpretation of Brass' P/F Ratio Method Applicable When Fertility is Declining*.

Fogel, R. W. (2004). *The escape from hunger and premature death, 1700-2100 : Europe, America, and the Third World*. Cambridge ; New York: Cambridge University Press.

Frejka, T., Jones, G. W., and Sardon, J.-P. (2010). East Asian Childbearing Patterns and Policy Developments. *Population and Development Review, 36*(3), 579-606. doi: 10.1111/j.1728-4457.2010.00347.x.

Gerland, P. (2013). *UN Population Division's Methodology in Preparing Base Population for Projections: case study for India*. Paper presented at the JYP Comparative Asia Research Centre, NUS Global Asia Institute Conference on “40 per cent of the world: population change, human capital and development in China, India and Indonesia”, Singapore.

Glei, D. A., and Horiuchi, S. (2007). The narrowing sex differential in life expectancy in high-income populations: effects of differences in the age pattern of mortality. *Population Studies, 61*(2), 141-159. doi: 10.1080/00324720701331433.

Goldstein, J. R., Sobotka, T., and Jasilioniene, A. (2009). The End of "Lowest□Low" Fertility? *Population and Development Review,* 35(4), 663-699. doi: 10.1111/j.1728-4457.2009.00304.x.

Heilig, G. K., Gerland, P., Li, N., Kantorova, V., Lattes, P., and Gjaltema, T. (2009). *The 2008 Revision of the United Nations World Population Prospects: Challenges in Estimating and Projecting the World's Population*. Paper presented at the XXVI IUSSP International Population Conference, Marrakech, Morocco. http://iussp2009.princeton.edu/download.aspx?submissionId=90664

Heuveline, P. (2003). HIV and Population Dynamics: A General Model and Maximum-Likelihood Standards for East Africa. *Demography, 40*(2), 217-245. doi: 10.2307/3180799.

Hill, K., Choi, Y., and Timaeus, I. (2005). Unconventional approaches to mortality estimation. *Demographic Research (on-line), 13*, 281-300.

__________, You, D., Inoue, M., Oestergaard, M. Z., and Technical Advisory Group of the United Nations Inter-agency Group for Child Mortality, E. (2012). Child Mortality Estimation: Accelerated Progress in Reducing Global Child Mortality, 1990–2010. *PLoS Med, 9*(8), e1001303. doi: 10.1371/journal.pmed.1001303.

Jones, G., Straughan, P., and Chan, A. (2008). *Ultra-low fertility in Pacific Asia: trends, causes and policy issues*: Taylor and Francis US.

Li, N., and Gerland, P. (2009). *Modelling and projecting the postponement of childbearing in low-fertility countries*. Paper presented at the XXVI IUSSP International Population Conference, Marrakech, Morocco. http://iussp2009.princeton.edu/download.aspx?submissionId=90315

__________, and Gerland, P. (2011). *Modifying the Lee-Carter Method to Project Mortality Changes up to 2100*. Paper presented at the Annual Meeting of the Population Association of America, Washington, DC. http://paa2011.princeton.edu/download.aspx?submissionId=110555

__________, Lee, R., and Gerland, P. (2013). Extending the Lee-Carter Method to Model the Rotation of Age Patterns of Mortality Decline for Long-Term Projections. *Demography, In press.*, 1-15. doi: 10.1007/s13524-013-0232-2.

London Summit on Family Planning. (2012). *Technical Note: Data sources and methodology for developing the 2012 baseline, 2020 objective, impacts and costings*. London:. http://www.londonfamilyplanningsummit.co.uk/

Lutz, W. (2007). The Future of Human Reproduction: Will Birth Rates Recover or Continue to Fall? *Ageing Horizons*(7), 15–21.

Masquelier, B. (2012). Adult Mortality From Sibling Survival Data: A Reappraisal of Selection Biases. *Demography, 50*(1), 1-22. doi: 10.1007/s13524-012-0149-1.

Meslé, F. (2004). [Gender gap in life expectancy: the reasons for a reduction of female advantage]. *Rev Epidemiol Sante Publique, 52*(4), 333.

Moultrie, T. A., Dorrington, R. E., Hill, A. G., Hill, K., Timæus, I. M., and Zaba, B. (Eds.). (2013). *Tools for Demographic Estimation*: International Union for the Scientific Study of Population.

Myrskylä, M., Goldstein, J. R., and Cheng, Y.-h. A. (2013). New Cohort Fertility Forecasts for the Developed World: Rises, Falls, and Reversals. *Population and Development Review, 39*(1), 31-56. doi: 10.1111/j.1728-4457.2013.00572.x.

__________, M., Kohler, H. P., and Billari, F. C. (2009). Advances in development reverse fertility declines. *Nature, 460*(7256), 741-743. doi: 10.1038/nature08230.

Obermeyer, Z., Rajaratnam, J. K., Park, C. H., Gakidou, E., Hogan, M. C., Lopez, A. D., and Murray, C. J. (2010). Measuring adult mortality using sibling survival: a new analytical method and new results for 44 countries, 1974-2006. *PLoS Med, 7*(4), e1000260. doi: 10.1371/journal.pmed.1000260.

Oeppen, J., and Vaupel, J. W. (2002). Demography. Broken limits to life expectancy. *Science, 296*(5570), 1029-1031. doi: 10.1126/science.1069675.

Oksuzyan, A., Juel, K., Vaupel, J. W., and Christensen, K. (2008). Men: good health and high mortality. Sex differences in health and aging. *Aging Clinical and Experimental Research, 20*(2), 91-102.

Pampel, F. (2005). Forecasting sex differences in mortality in high income nations: The contribution of smoking. *Demographic Research, 13*(18), 455. doi: 10.4054/DemRes.2005.13.18.

Preston, S. H., Heuveline, P., and Guillot, M. (2001). *Demography: measuring and modeling population processes*. Malden, MA: Blackwell Publishers.

Raftery, A., Alkema, L., Gerland, P., Clark, S., Pelletier, F., Buettner, T., and . Sevcikova, H. (2009). *White Paper: Probabilistic Projections of the Total Fertility Rate for All Countries for the 2010 World Population Prospects*. Paper presented at the Expert Group Meeting on Recent and Future Trends in Fertility, New York, NY. http://www.un.org/esa/population/meetings/EGM-Fertility2009/P16_Raftery.pdf

__________, Alkema, L., and Gerland, P. (2013). Bayesian Population Projections for the United Nations. *Statistical Science, in press*. doi: http://www.epublications.org/ims/submission/index.php/STS/user/submissionFile/13954?confirm=bafd1514

__________, Chunn, J. E., Gerland, P., and Ševčíková, H. (2013). Bayesian Probabilistic Projections of Life Expectancy for All Countries. *Demography, 50*(3), 777-801. doi: 10.1007/s13524-012-0193-x.

__________, Lalic, N., and Gerland, P. (2012). *Joint Probabilistic Projection of Female and Male Life Expectancy*. Paper presented at the Annual Meeting of the Population Association of America, San Francisco, CA. http://paa2012.princeton.edu/download.aspx?submissionId=120140

__________., Li, N., Ševčíková, H., Gerland, P., and Heilig, G. K. (2012). Bayesian probabilistic population projections for all countries. *Proceedings of the National Academy of Sciences, 109*(35), 13915-13921. doi: 10.1073/pnas.1211452109.

Rajaratnam, J. K., Marcus, J. R., Levin-Rector, A., Chalupka, A. N., Wang, H., Dwyer, L., and . Murray, C. J. (2010). Worldwide mortality in men and women aged 15-59 years from 1970 to 2010: a systematic analysis. *Lancet, 375*(9727), 1704-1720. doi: 10.1016/S0140-6736(10)60517-X.

Riley, J. C. (2001). *Rising life expectancy: a global history*. Cambridge; New York: Cambridge University Press.

Rogers, R. G., and Crimmins, E. M. (Eds.). (2011). *International Handbook of Adult Mortality* (Vol. 2). Netherlands: Springer.

__________, Everett, B. G., Saint Onge, J. M., and Krueger, P. M. (2010). Social, behavioral, and biological factors, and sex differences in mortality. *Demography, 47*(3), 555-578.

Ryder, N. B. (1964). The Process of Demographic Translation. *Demography, 1*(1), 74-82. doi: 10.2307/2060032.

__________ (1983). Cohort and period measures of changing fertility. In R. A. Bulatao, R. D. Lee and National Research Council (U.S.). Committee on Population and Demography. Panel on Fertility Determinants. (Eds.), *Determinants of fertility in developing countries* (pp. 737-756). New York: Academic Press.

Sawyer, C. C. (2012). Child Mortality Estimation: Estimating Sex Differences in Childhood Mortality since the 1970s. *PLoS Med, 9*(8), e1001287. doi: 10.1371/journal.pmed.1001287.

Ševčíková, H., Alkema, L., and Raftery, A. E. (2011). bayesTFR: An R package for probabilistic projections of the total fertility rate. *Journal of Statistical Software, 43*(1), 1-29.

Sobotka, T. (2011). Fertility in Central and Eastern Europe after 1989: Collapse and Gradual Recovery. *Historical Social Research-Historische Sozialforschung, 36*(2), 246-296.

Spoorenberg, T., and Schwekendiek, D. (2012). Demographic Changes in North Korea: 1993-2008. *Population and Development Review, 38*(1), 133-+. doi: 10.1111/j.1728-4457.2012.00475.x.

Stanecki, K., Garnett, G. P., and Ghys, P. D. (2012). Developments in the field of HIV estimates: methods, parameters and trends. *Sexually Transmitted Infections, 88*(Suppl 2), i1-i2. doi: 10.1136/sextrans-2012-050885.

Stover, J., Brown, T., and Marston, M. (2012). Updates to the Spectrum/Estimation and Projection Package (EPP) model to estimate HIV trends for adults and children. *Sex Transm Infect, 88 Suppl 2*, i11-16. doi: 10.1136/sextrans-2012-050640.

Swanson, D., and Siegel, J. S. (Eds.). (2004). *The methods and material of demography* (2st ed.). San Diego, CA: Academic Press.

Thatcher, A. R., Kannisto, V., and Vaupel, J. W. (1998). *The Force of Mortality at Ages 80 to 120*.

Trovato, F., and Heyen, N. (2006). A varied pattern of change of the sex differential in survival in the G7 countries. *Journal of Biosocial Science, 38*(3), 391. doi: 10.1017/S0021932005007212.
__________, and Lalu, N. (1996). Narrowing sex differentials in life expectancy in the industrialized world: early 1970's to early 1990's. *Biodemography and Social Biology, 43*(1-2), 20-37.
__________, and Lalu, N. (1998). Contribution of cause specific mortality to changing sex differences in life expectancy: Seven nations case study. *Biodemography and Social Biology*, 45(1-2), 1-20.
UNAIDS. (2012). Global report: UNAIDS report on the global AIDS epidemic 2012 (pp. 210). Geneva, Switzerland: Joint United Nations Programme on HIV/AIDS.
United Nations. (1982). *Model life tables for developing countries*. New York: United Nations.
__________ (1983). *Manual X: indirect techniques for demographic estimation* (Vol. 81). New York: United Nations.
__________ (1989). *World Population Prospects 1988* (Vol. 106). New York: United Nations.
__________ (2002). *Methods for estimating adult mortality*. New York: United Nations.
__________ (2006). *World Population Prospects: The 2004 Revision, Volume III: Analytical Report* (Vol. ST/ESA/SER.A/246). New York: Department of Economic and Social Affairs.
__________ (2008). *Principles and recommendations for population and housing censuses/ Department of Economic and Social Affairs, Statistics Division* (Rev. 2 ed.). New York: United Nations .
__________ (2010). Methodology of the United Nations population estimates and projections *World Population Prospects: The 2006 Revision, Volume III: Analytical Report* (ST/ESA/SER.A/263, pp. 121-159). New York: Department of Economic and Social Affairs, Population Division.
Vallin, J. (2006). Mortality, Sex, and Gender. In G. Caselli, J. Vallin and G. J. Wunsch (Eds.), *Demography : analysis and synthesis* (Vol. II, pp. 177-194). Amsterdam ;Boston: Elsevier.
__________, and Mesle, F. (2009). The Segmented Trend Line of Highest Life Expectancies. *Population and Development Review, 35*(1), 159-+. doi: 10.1111/j.1728-4457.2009.00264.x.
Vaupel and Kistowski, K. G. v. (2005). Broken Limits to Life Expectancy. *Ageing Horizons*(3), 6-13.
Wang, H., Dwyer-Lindgren, L., Lofgren, K. T., Rajaratnam, J. K., Marcus, J. R., Levin-Rector, A., Murray, C. J. (2012). Age-specific and sex-specific mortality in 187 countries, 1970-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet, 380*(9859), 2071-2094. doi: 10.1016/S0140-6736(12)61719-X.
Whelpton, P. K. (1936). An Empirical Method of Calculating Future Population. *Journal of the American Statistical Association, 31*(195), 457-473. doi: 10.2307/2278370.
Wilmoth, J. R., Deegan, L. J., Lundstrom, H., and Horiuchi, S. (2000). Increase of maximum life-span in Sweden, 1861-1999. *Science, 289*(5488), 2366-2368.
__________, and Ouellette, N. (2012, 13-16 June). *Maximum human lifespan: Will the records be unbroken?*, Stockholm, Sweden.
__________, and Robine, J.M. (2003). The world trend in maximum life span. In J. R. C. a. S. Tuljapurkar (Ed.), *Life Span: Evolutionary, Ecological, and Demographic Perspectives* (Vol. supplement to vol. 29, pp. 239–257): Population and Development Review.
Wolfgang Lutz, Skirbekk, V., and Testa, M. R. (2006). The Low Fertility Trap Hypothesis: Forces that May Lead to Further Postponement and Fewer Births in Europe *Vienna Yearbook of Population Research, 4* (Postponement of Childbearing in Europe), 167-192. doi: 10.1553/populationyearbook2006s167