Session V:
Projecting the level and pattern of mortality
9 March 2016

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Population Estimates and Projections Section

www.unpopulation.org
Outline

I. Inputs needed for projecting mortality
II. Life table refresher
III. Establishing the baseline of mortality
IV. Considerations around HIV/AIDS mortality
V. Projecting the level of mortality
VI. Projecting the age pattern of mortality
Inputs needed for projecting mortality

- To project population from one date to the next, cohort component method requires age-sex specific survivorship ratios \((\frac{5L_x}{5L_{x-5}})\)
- Unless assuming constant mortality, need to provide input survival ratios for each year/period of the projection
- Projection software packages simplify the inputs required, decompose into 2 components:
  - Life expectancy trend by sex
  - Age pattern of mortality by sex
    - Packages allow for inputs at limited years and scale pattern to input life expectancies
Life table refresher
The period life table – Example (Preston et al. 2001)

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Calculating the period (abridged) life table

1. Age-specific death rate ($nM_x$)
   
   $$nM_x = \frac{nD_x}{nN_x}$$

2. Probability of dying between ages $x$ and $x+n$ ($nq_x$)
   
   **>> assuming that persons dying in the interval do so, on average, half-way through the interval**

   $$nq_x = \frac{2n \cdot nM_x}{2 + n \cdot nM_x}$$

   For open-ended age group $\infty q_x = 1$

3. Probability of surviving from one age to the next ($nP_x$)

   $$nP_x = 1 - nq_x$$
Calculating the period (abridged) life table

4. Number surviving at exact ages ($l_x$) →

\[ l_{x+n} = l_x \cdot n \cdot p_x \]
\[ l_{x+n} = l_x - n \cdot d_x \]

>> At age 0, $l_0 = 100,000$

5. Deaths between ages $x$ and $x+n$ ($d_x$) →

\[ n \cdot d_x = l_x \cdot n \cdot q_x \]
\[ n \cdot d_x = l_x - l_{x+n} \]
Calculating the period (abridged) life table

6. Average number alive between exact ages $x$ and $x+n (\ell_x)$

$$nL_x = \frac{n}{2} \cdot (l_x + l_{x+n})$$

For $L_0$,  

$$L_0 = 0.3l_0 + 0.7l_1$$

For open-ended age group

7. Total population aged $x$ and over ($T_x$)

$$T_x = \sum_{i=x}^{\infty} nL_i$$

For open-ended age group

$$T_x = \ell_x$$

Working from the bottom of the life table

$$T_x = T_{x+n} + nL_x$$
Calculating the period (abridged) life table

8. Expectation of life from age \( x \) \( (e_x) \)

\[ e_x = \frac{T_x}{l_x} \]

\[ \rightarrow \text{Life expectancy at birth } (e_0) = \frac{T_0}{l_0} \]
Example – using MortPak LIFTB
Central African Republic, 1988 Census, Men

Establishing the baseline of mortality
Establishing the baseline of mortality

Projection programs’ input requirements:
  o Level of $e_0$ by sex
  o Age pattern of mortality
    – Empirical pattern?
    – Model life table pattern?

Available from the census are usually:
  o Household deaths
  o Census estimates of children ever born/surviving

Supplemental data from surveys:
  o Birth histories
  o Sibling histories
  o Household deaths (occasionally)

Focus on straightforward methods to analyze/compare readily available data
Child mortality

- Calculation techniques for Brass-type estimates were covered in October workshop
- Evaluate census estimates of under-five mortality
- Consider census estimates together with other sources of data
Establishing the baseline of mortality

Quality of estimates:
Comparison with existing external sources

Central African Republic

UN Population Division
(World Population Prospects)

Source: http://esa.un.org/unpd/wpp/DVD/
But wait!

- Projections require **sex-specific** mortality input
- Option 1: calculate estimates from data by sex of child
  - Estimates by sex from different sources tend to be more erratic than estimates for both sexes combined
  - Keep in mind that DHS estimates by sex refer to a 10-year period before the survey
- Option 2: use modelled sex ratios of under-five and infant mortality from UN-IGME
# Sex ratios of under-five and infant mortality

## Under-five mortality by sex

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## Infant mortality by sex

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Source: Estimates generated by the UN Inter-agency Group for Child Mortality Estimation (IGME) in 2015.
Downloaded from http://www.childmortality.org
Converting from $5q_0$ for both sexes to $5q_0$ by sex

\[ 5q_0_{\text{male}} = 5q_0_{\text{both}} \times \frac{1 + SRB}{(SRB + 1/ SR5_t)} \]

and

\[ 5q_0_{\text{female}} = \frac{5q_0_{\text{male}}}{SR5_t} \]

$SRB$ = Male/female ratio at birth (e.g. 1.03)

$SR5_t$ = Male/female ratio of $5q_0$ (e.g. 1.20)
Approaches to $m_x$ at ages 5+

- Investigate reported age-specific mortality from available sources
  - Household deaths from censuses
  - Sibling deaths from DHS (ages 15-49)
- May want to smooth $m_x$
- May try converting to summary indicator
  - $45q_{15}$, $35q_{15}$
- Keep in mind that mortality at oldest ages (~60+) is very likely underreported
  - Consider adjusting baseline pattern at these ages
Mortality at ages 5+

Reported age-specific death rates, Tanzania 2002

mx

Age

Census Male  Census Female  DHS Female  DHS Male
Calculated and smoothed $m_x$

**COUNTRY: YEAR**

1. Age-Specific Central Death Rates

**PASEX workbook**

**LTPOPDTH.xls**
Calculating summary indicators of adult mortality

- Two commonly used summary indicators of adult mortality are

\[ 45q_{15} = \frac{(l_{15} - l_{60})}{l_{15}} \]

\[ 35q_{15} = \frac{(l_{15} - l_{50})}{l_{15}} \]  

Indicator available from DHS sibling histories
Summary indicators can be useful to assess suitability of models

Relationship between $5q_0$ and $45q_{15}$ in standard model life tables
Getting to an input life table: useful Mortpak applications

- CORMOR: examine relationships between mortality indicators in different model life table families
- MATCH: obtain a life table from one indicator and a model choice
- COMBIN: “splice” empirical estimates of infant, under-five and adult mortality indicators; choose a model to use in the fitting
Note on age patterns for projection software packages

- Spectrum DemProj: model life tables only; model choice is constant throughout projection
  (there is an advanced option for a user-defined life table pattern but it is very cumbersome)

- RUP: accepts user-defined $m_x$ values; different patterns can be input for base year and later years
Considerations around HIV/AIDS mortality
Mortality from HIV/AIDS

- Existing mortality model patterns inadequate for AIDS mortality (new cause of death concentrated in young-middle adult age groups, with impact on child mortality as well).
- Dynamic nature of the HIV epidemic with long asymptomatic phase.
- Age pattern of mortality depends not only of the age of individuals, but also on the duration since infection, the past prevalence, the sex ratio of infection, and access to treatment.
- Compartmental/multistate modelling of HIV epidemic, and various stages of HIV infection until AIDS death or survival with ART.
Impact of HIV/AIDS on mortality

Age-specific mortality, Botswana males, 1980-85 and 2000-05

World Population Prospects approach to mortality estimation/projection in high-HIV settings

- 21 countries with high HIV prevalence
- Model HIV incidence and mortality explicitly since the beginning of the epidemic
- Using model developed by UNAIDS Reference Group on Estimates, Modelling and Projections
- Epidemiological parameters as supplied by UNAIDS in Spectrum
  - Incidence
  - Age pattern of incidence
  - Adult treatment
  - Pediatric treatment
  - Mother-to-child transmission
  - Etc.
Alternative approaches seen in national projections

- Model life tables with AIDS (e.g. InDepth)
  - Have not been used by UN
- Empirical pattern from e.g. most recent census may be acceptable for short term projection
Mortality in the age of widespread ART


Projecting the level of mortality: The United Nations model
Mortality change (and fertility change) are processes where new behavior is gradually being adopted by people. It is similar to the processes of a new product penetrating a market. In other words: A **diffusion process**.

Diffusion processes are often modeled by a **logistic function**.
A logistic function exhibits an S-shape and describes a diffusion process growing from an initial level to an upper or lower asymptote.

Logistic curve of the hypothetical increase in life expectancy at birth
How fast should we expect life expectancy to change?

- Life expectancy at birth for 201 countries, 1950-55 to 2010-15

Overall increase in e0 over time for most countries
The top gainers had rapid advances in $e_0$...

- Life expectancy at birth for countries in **highest quintile** of increase between 1950-55 and 2010-15

Top quintile of gains: these 40 countries gained between 28-42 years of $e_0$
...while gains in the lowest quintile were far slower, or interrupted

- Life expectancy at birth for countries in lowest quintile of increase between 1950-55 and 2010-15

Lowest quintile of gains: these 40 countries gained between 6-14 years of $e_0$
Today’s countries with highest $e_0$ have seen 7-33 years of gain since 1950s

- Life expectancy at birth for highest quintile in 2010-2015

Several of today’s leading countries were not in the top list in 1950s
Implications for modelling

- Different paces of change for countries at similar level of $e_0$
- Progress is still possible at high levels of $e_0$, but absolute gains are smaller
- UN model: logistic fit to pace of change, rather than level of life expectancy
United Nations MorModel: Two-phase decline

- The demographic process of decline in mortality (and fertility) consists of two phases:
  - a first phase of accelerating rates of decline
  - a second phase of slowing rates of decline.

- Modelled as the sum of 2 logistic functions
  - First approaching upper limit
  - Second approaching lower limit

\[
P(t) = \frac{k_1}{1 + \exp\left[-\frac{\ln(81)}{\Delta t_1} (t - t_{m1})\right]} \quad + \quad \frac{k_2}{1 + \exp\left[-\frac{\ln(81)}{\Delta t_2} (t - t_{m2})\right]}\]
Bi-logistic illustrated

Average annual change in life expectancy by level of life expectancy

Life expectancy at birth

Average annual change
Modelling approach

- Analysis of past average annual gains in life expectancy at birth ($e_0$) by sex given level of $e_0$
- Sample selection: all countries with normal mortality transition (i.e., AIDS countries/periods excluded) to get trajectories reflecting the experience for a broad range of situations
- 5 different typical trajectories of the pace of improvements in life expectancy were developed and are used to project future $e_0$
Derivation of the model patterns
Models for males and females

Pace of change

**Very fast**
**Fast pace**
**Medium Pace**
**Slow pace**
**Very slow**

Based on the average gains of...

**Upper Decile**
**Upper Quartile**
**Arithmetic mean**
**Lower Quartile**
**Lower Decile**
Gains over time starting at e0 of 40

Model trajectories of gains in $e_0$, Males (low $e_0$)
Gains over time starting at e0 of 75

Model trajectories of gains in (e_0), Males (high (e_0))
UNPD_MorModel_v.1.xlsm

1. Enter description
2. Enter your data
3. Select a model for each sex
Projected life expectancy at birth

UNPD_MorModel_v.1.xlsm
Projecting the level of mortality: The US Census Bureau model
EOLGST.xls – Logistic model

- Interpolates and extrapolates life expectancies at birth, by sex.
- Input time series of 2 to 17 life expectancies at birth
- Provide upper and lower asymptotes.
- Projected level depends on asymptote, trend in fitted points
### EOLGST.xls – Logistic model

#### Table: Interpolation and Extrapolation of Life Expectancies at Birth, by Sex, Using a Logistic Function.

<table>
<thead>
<tr>
<th>Item or year</th>
<th>Male</th>
<th>Female</th>
<th>Both sexes</th>
<th>Male</th>
<th>Female</th>
<th>Both sexes</th>
<th>Male</th>
<th>Female</th>
<th>Both sexes</th>
<th>Male</th>
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<th>Both sexes</th>
<th>Male</th>
<th>Female</th>
<th>Both sexes</th>
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</thead>
<tbody>
<tr>
<td>Asymptotes:</td>
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<tr>
<td>Lower</td>
<td>25.00</td>
<td>25.00</td>
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<tr>
<td>Upper</td>
<td>82.66</td>
<td>88.40</td>
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<tr>
<td>Life expectancy at birth:</td>
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<tr>
<td>1960.50</td>
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<td>60.00</td>
<td></td>
<td>57.44</td>
<td>5.00</td>
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<tr>
<td>1980.40</td>
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<td>59.95</td>
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<td>64.04</td>
<td></td>
<td>63.96</td>
<td>61.60</td>
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</tbody>
</table>

Source:
Projecting the age pattern of mortality
Mortality age pattern projection

- While some data-intensive approaches are possible in settings with long time series of age-specific mortality data, minimalist approaches serve well in settings with less data.

General approach:

Project life expectancy first and choose from among options for future age pattern:

1. Use a single model life table choice for the whole projection.

2. Input an empirical pattern for the base period. Let the projection program scale it to input life expectancy for each period of the projection.
3. Input an empirical pattern for the base year. Assume that the age pattern of mortality will converge to a different “target pattern” for the end of the projection – this could be a model pattern matched to the level of life expectancy projected for the final period.

4. Another approach is to select an “ultimate life table” far in the future (after the end of the projection horizon). The projection program will interpolate the intermediate age patterns scaled to the input life expectancy.
Thank you

Questions?

>> until 11 March:

>> After 11 March: sawyerc@un.org
    bassarsky@un.org
World Population Prospects: The 2015 Revision $e_0$ estimates
World Population Prospects: The 2015 Revision e₀ estimates

Ghana

Kenya

[Graphs showing population trends for Ghana and Kenya over the years.]
World Population Prospects: The 2015 Revision $e_0$ estimates