Exploring the HALE Estimates of the Global Burden of Disease Study by a Simple, Gompertz, Weibull and an advanced IM model

Christos H. Skiadas

ManLab, Technical University of Crete, Chania, Crete, Greece

skiadas@cmsim.net
What is Health and Health Status

- According to the World Health Organization (WHO)
  "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

- Physical health
- Mental health
- More....

"We must turn to nature itself, to the observations of the body in health and in disease to learn the truth."

(Hippocrates)
Determinants of health

- Socioeconomic status
- Education
- Physical environment
- Job prospects and employment conditions
- Support from people around you
- Culture
- Genetic inheritance
- What we do and how we manage
- Access and use of health services
- Gender

"It is health that is real wealth and not pieces of gold and silver."

(Mahatma Gandhi)
World Health Organization (WHO) and Health and Disease Measures

- The STEPS Instrument and Support Materials
- THE STEPS INSTRUMENT
- The tool used to collect data and measure noncommunicable disease (NCD) risk factors within the WHO STEPwise approach to surveillance is called the STEPS Instrument. The STEPS Instrument covers three different levels or 'steps' of risk factor assessment:
  - Step 1 (questionnaire),
  - Step 2 (physical measurements) and
  - Step 3 (biochemical measurements).
Global Physical Activity Surveillance
WHO Questionnaires

- Physical Activity
- Questions
- Activity at work
- Travel to and from places
- Recreational activities
- Sedentary behaviour
- Other…
The Global Burden of Disease Study

- The GBD 2000 project has adopted a similar approach to health state valuation, using a
- standard health state description based on eight core domains of health (mobility, self care,
- pain and discomfort, cognition, interpersonal activities, vision, sleep and energy, affect).
- As part of the World Health Survey being conducted by WHO (WHO, 2003), revised
- disability weights will be developed during 2003 that are based on health state valuations
- from large representative population samples in over 70 countries.
Our View of the Problem
Find a simple method measuring our health state


- People have an estimate of their health state
- How this is done?
- By observing the overall social health status and especially the Determinants of health presented earlier
- These hundreds, thousands or millions influences form the overall public opinion. The most important part refers to the most critical issue that of live and die and the information coming from the environment.
- People give their responses.
- Can we find a simple way to reproduce it?
The Mortality Diagram

is constructed by using the force of mortality $\mu_x$


1. The Mortality Area (OCABO)
2. The Health Area (ODACO)
3. The Total Area (ODABO)
4. Equation $\mu_x = \left(\frac{x}{T}\right)^b$
5. $E_{mortality} = \frac{T}{(b + 1)}$
   $E_{health} = \frac{bT}{b + 1}$
   $\frac{E_{health}}{E_{mortality}} = b$
   $\frac{E_{total}}{E_{mortality}} = b + 1$
The Mortality Diagram

\[ \mu_x \text{ and } (1-\mu_x) \]
The Main Finding

We have used a Geometric approach to develop the parameter $b$

We can arrive to the Loss of Healthy Life Years of a Population by estimating the Parameter $b$ presented earlier.

The only needed is information for the mortality of the population $\mu x$.

Fortunately this information is provided in all the Life Tables from the days of John Graunt (1661) and Edmont Halley (1693).

$$LHLY = \lambda \frac{E_{health}}{E_{mortality}} = b \lambda$$
The Main Finding

The parameter $b$ expresses the Loss of Healthy Life Years (LHLY)

- We check the LHLY estimated by our method with that of the WHO
- For comparisons between countries it is sufficient to select $\lambda=1$.
- To our great surprise selecting $\lambda=1$ provided results very close to those provided by WHO as it is presented in the following Tables and in other applications. It is clear that we have found an interesting estimator for the loss of healthy life years.

\[
\frac{E_{health}}{E_{mortality}} = b
\]
Estimation without a model from $mx$

As the needed data sets in the form of $mx$ or $qx$ data are provided from the life tables, we have developed a method of direct estimation of the loss of healthy life year estimators directly from the life table by expanding the life table to the right.

The only needed is to estimate the following fraction from the life table data:

$$b = \frac{E_{\text{total}}}{E_{\text{mortality}}} = \frac{xm_x}{\sum_0^\infty m_x}$$
Estimation without a model from \( qx \)

A similar indicator results by selecting the \( qx \) data from the life table and using the:

\[
b = \frac{E_{\text{total}}}{E_{\text{mortality}}} = \frac{xq_x}{\sum_0^x q_x}
\]
Fig. Estimation of the HLYL indicator \((b)\) by the direct method and by the simple model (Full results A and expanded around the maximum B)
Estimation with and without a model from \textit{mx} (Direct and Model estimation)

\begin{figure}
\centering
\includegraphics[width=\textwidth]{hlyl_indicator.png}
\caption{Estimation of the HLYL indicator \((b)\) by the direct method and by the simple model}
\end{figure}
More details: The Gompertz and the Weibull Distributions

\[ f_x = e^{-k+bx} - e^{-l+bx} \]

Gompertz (\( l \) parameter is expressing the HLYL)

\[ f_x = \frac{b}{T} \left( \frac{x}{T} \right)^{b-1} e^{-\left( \frac{x}{T} \right)^b} \]

Weibull

\[ H(x) = \left( \frac{x}{T} \right)^b \]

Weibull Cumulative Hazard (\( b \) parameter)
A second order approximation in the following form can improve fitting:

\[ f_x = \left( \frac{2}{\sqrt{2\pi}} \right) \left( \frac{|H_x - xH'_x|}{\sqrt{x^3}} - \frac{k\sqrt{x^3}H''_x}{2|H_x - xH'_x|} \right) e^{-\frac{H_x^2}{2x}} \]

- The parameter \( k \) expresses the level of the influence of the second order correction term. When \( k=0 \) the last equation form reduces to the first order approximation.
The Health Function

\[ H(x) = l - (bx)^c \]

- Insert the 3-parameter \((b, l, c)\) expression introduced by Skiadas and Skiadas [2] for \(H(x)\) in the previous general model we find the following 4-parameter IM-model:

\[
 f_x = \left( \frac{2}{\sqrt{2\pi}} \right) \left( \frac{l + (c - 1)(bx)^c}{\sqrt{x^3}} + \frac{k\sqrt{x^3}c(c - 1)b^cx^{(c-2)}}{2\left( l + (c - 1)(bx)^c \right)} \right) e^{-\frac{(l-(bx)^c)^2}{2x}}
\]

- The importance in this model is that the exponent \(c\) is related to the healthy life years lost by:

\[ \text{HLYL} = c - 0.5 + \ln(c-1) \]
More details: The SKI-IM Model
Fitting the 4-Parameter Model
Total Methods and Models used

1. Direct estimation
2. Simple Model
3. Gompertz Model
4. Weibull Model
5. SKI-IM Model
Estimation with and without a model from \textit{mx} (Direct, SKI-IM, Weibull and Gompertz)
Estimation with and without a model from $mx$ (Direct, SKI-IM, Weibull and Gompertz)

Healthy Life Years Lost (Austria, females)

<table>
<thead>
<tr>
<th>Year</th>
<th>HLYL (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>7.00</td>
</tr>
<tr>
<td>1950</td>
<td>8.00</td>
</tr>
<tr>
<td>1960</td>
<td>9.00</td>
</tr>
<tr>
<td>1970</td>
<td>10.00</td>
</tr>
<tr>
<td>1980</td>
<td>11.00</td>
</tr>
<tr>
<td>1990</td>
<td>12.00</td>
</tr>
<tr>
<td>2000</td>
<td>13.00</td>
</tr>
<tr>
<td>2010</td>
<td>14.00</td>
</tr>
<tr>
<td>2020</td>
<td>15.00</td>
</tr>
</tbody>
</table>

- **Weibull**
- **Gompertz**
- **SKI-IM**
- **Direct estimation**
- **WHO estimates**
Healthy Life Years Lost at birth in Japan (males)

HLYL (Years)


mx estimates (b+1) mx estimates (b) qx estimates (b+1)
qx estimates (b) WHO estimates

Year

Loss of Healthy Life Years

Fig. 2A. Loss of Healthy Life Years in Czech Republic (1950-2010)

Fig. 2B. Loss of Healthy Life Years in Switzerland (1880-2010)
Percentage of Life Expectancy Lost

Percentage of Total Life Expectancy Lost in Czech Republic

Percentage of Life Expectancy Lost in Switzerland

- Males
- Females
Fig. 3. The gap between males and females for Czech Republic
Healthy Life Expectancy

Fig. 4A. Healthy Life Expectancy in Czech Republic (1950-2010)

Fig. 4B. Healthy Life Expectancy in Switzerland (1880-2010)
Loss of Healthy Life Years and Healthy Life Expectancy in Belgium
Percentage of Life Expectancy Lost

Percentage of Life Expectancy Lost in Denmark (1835-2011)

- Males
- Females
Loss of Healthy Life Years
The Life Table

The program produces estimates of Healthy Life Expectancy (HLE) with our Model to compare with the World Health Organization (WHO) estimates.

The maximum number of data points introduced is 22. The program will calculate automatically the model parameters: b and T.

Verifying the HALE measures of the Global Burden of Disease Study: A New Mortality Model for Estimating the Loss of Healthy Life Years and the Healthy Life Expectancy from the Abridged Life Table (0-100) Provided by the World Health Organization (WHO)

The Abridged Life Table Including Life Expectancy, Loss of Healthy Life Years and Healthy Life Expectancy Estimation

<table>
<thead>
<tr>
<th>Age Category</th>
<th>Morality</th>
<th>Life Expectancy Estimation</th>
<th>Healthy Life Expectancy Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Life Expectancy</td>
<td>Mortality from life table (T)</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>(μx) x</td>
<td>106.8</td>
</tr>
</tbody>
</table>

Data Introduction

<table>
<thead>
<tr>
<th>Age Category</th>
<th>Mortality</th>
<th>100,000 population</th>
<th>lx and x</th>
<th>Survival</th>
<th>Lx</th>
<th>Tx</th>
<th>es</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0003919</td>
<td>0.00390</td>
<td>100000</td>
<td>390</td>
<td>99,649</td>
<td>8,007,053</td>
<td>50.8</td>
</tr>
<tr>
<td>1</td>
<td>0.000176</td>
<td>0.00070</td>
<td>960000</td>
<td>70</td>
<td>308,299</td>
<td>7,977,404</td>
<td>68.0</td>
</tr>
<tr>
<td>5</td>
<td>0.000061</td>
<td>0.00054</td>
<td>964000</td>
<td>34</td>
<td>497,613</td>
<td>7,679,100</td>
<td>70.4</td>
</tr>
<tr>
<td>10</td>
<td>0.000047</td>
<td>0.00047</td>
<td>950000</td>
<td>47</td>
<td>497,410</td>
<td>7,681,493</td>
<td>71.7</td>
</tr>
<tr>
<td>15</td>
<td>0.000357</td>
<td>0.0178</td>
<td>964000</td>
<td>61</td>
<td>496,814</td>
<td>7,683,344</td>
<td>71.0</td>
</tr>
<tr>
<td>20</td>
<td>0.000423</td>
<td>0.0211</td>
<td>962000</td>
<td>77</td>
<td>496,681</td>
<td>7,688,976</td>
<td>71.4</td>
</tr>
<tr>
<td>25</td>
<td>0.000451</td>
<td>0.0240</td>
<td>960000</td>
<td>91</td>
<td>496,508</td>
<td>7,693,888</td>
<td>71.8</td>
</tr>
<tr>
<td>30</td>
<td>0.000537</td>
<td>0.0258</td>
<td>958000</td>
<td>105</td>
<td>496,108</td>
<td>7,699,092</td>
<td>72.2</td>
</tr>
<tr>
<td>35</td>
<td>0.000633</td>
<td>0.0344</td>
<td>956000</td>
<td>120</td>
<td>495,508</td>
<td>7,704,795</td>
<td>72.6</td>
</tr>
<tr>
<td>40</td>
<td>0.001241</td>
<td>0.0622</td>
<td>952000</td>
<td>135</td>
<td>494,908</td>
<td>7,710,091</td>
<td>73.0</td>
</tr>
<tr>
<td>45</td>
<td>0.001854</td>
<td>0.0923</td>
<td>950000</td>
<td>155</td>
<td>494,308</td>
<td>7,715,194</td>
<td>73.4</td>
</tr>
<tr>
<td>50</td>
<td>0.003014</td>
<td>0.1464</td>
<td>947000</td>
<td>175</td>
<td>493,708</td>
<td>7,720,114</td>
<td>73.8</td>
</tr>
<tr>
<td>60</td>
<td>0.005096</td>
<td>0.2517</td>
<td>938000</td>
<td>215</td>
<td>492,708</td>
<td>7,725,378</td>
<td>74.2</td>
</tr>
<tr>
<td>70</td>
<td>0.007033</td>
<td>0.3899</td>
<td>927000</td>
<td>255</td>
<td>491,608</td>
<td>7,730,120</td>
<td>74.6</td>
</tr>
<tr>
<td>80</td>
<td>0.012872</td>
<td>0.6237</td>
<td>916000</td>
<td>305</td>
<td>490,708</td>
<td>7,735,200</td>
<td>75.0</td>
</tr>
<tr>
<td>90</td>
<td>0.019901</td>
<td>0.9479</td>
<td>903000</td>
<td>355</td>
<td>489,808</td>
<td>7,740,380</td>
<td>75.4</td>
</tr>
<tr>
<td>100</td>
<td>0.035588</td>
<td>1.8340</td>
<td>889000</td>
<td>405</td>
<td>489,008</td>
<td>7,745,640</td>
<td>75.8</td>
</tr>
<tr>
<td></td>
<td>0.065744</td>
<td>2.8232</td>
<td>872000</td>
<td>455</td>
<td>488,208</td>
<td>7,750,900</td>
<td>76.2</td>
</tr>
<tr>
<td>110</td>
<td>0.117572</td>
<td>4.5372</td>
<td>853000</td>
<td>505</td>
<td>487,408</td>
<td>7,756,250</td>
<td>76.6</td>
</tr>
<tr>
<td>120</td>
<td>0.202897</td>
<td>8.0357</td>
<td>832000</td>
<td>555</td>
<td>486,608</td>
<td>7,761,700</td>
<td>77.0</td>
</tr>
<tr>
<td>130</td>
<td>0.322161</td>
<td>15.7711</td>
<td>810000</td>
<td>605</td>
<td>485,808</td>
<td>7,767,250</td>
<td>77.4</td>
</tr>
<tr>
<td>140</td>
<td>0.437585</td>
<td>25.4811</td>
<td>788000</td>
<td>655</td>
<td>485,008</td>
<td>7,772,900</td>
<td>77.8</td>
</tr>
</tbody>
</table>

Main References


More References

Murray, C. J. L. et al. Global, regional, and national disability-adjusted life years (DALYs) for 369 diseases and injuries and healthy life expectancy (HALE) for 195 countries, 1990-2010: quantifying the epidemiological transition. The Lancet. August 2015. DOI: http://dx.doi.org/10.1016/S0140-6736(15)60505-9
## Comparing WHO (HALE) Results

<table>
<thead>
<tr>
<th>Sex/Region</th>
<th>Healthy Life Expectancy at Birth</th>
<th>Life Expectancy at Birth (LE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WHO (HALE)</td>
<td>Mortality Model</td>
</tr>
<tr>
<td><strong>Both sexes combined</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>58.0</td>
<td>58.4</td>
</tr>
<tr>
<td>High income countries</td>
<td>67.3</td>
<td><strong>67.1</strong></td>
</tr>
<tr>
<td>African Region</td>
<td>43.1</td>
<td><strong>42.8</strong></td>
</tr>
<tr>
<td>Region of the Americas</td>
<td>64.9</td>
<td>65.7</td>
</tr>
<tr>
<td>Eastern Mediterranean Region</td>
<td>55.4</td>
<td>56.9</td>
</tr>
<tr>
<td>European Region</td>
<td>63.9</td>
<td><strong>63.9</strong></td>
</tr>
<tr>
<td>South East Asian Region</td>
<td>54.2</td>
<td>56.3</td>
</tr>
<tr>
<td>Western Pacific Region</td>
<td>64.8</td>
<td><strong>63.9</strong></td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>56.4</td>
<td>56.6</td>
</tr>
<tr>
<td>High income countries</td>
<td>64.7</td>
<td>64.1</td>
</tr>
<tr>
<td>African Region</td>
<td>42.4</td>
<td>41.6</td>
</tr>
<tr>
<td>Region of the Americas</td>
<td>62.7</td>
<td>63.1</td>
</tr>
<tr>
<td>Eastern Mediterranean Region</td>
<td>54.8</td>
<td>55.7</td>
</tr>
<tr>
<td>European Region</td>
<td>60.7</td>
<td><strong>60.4</strong></td>
</tr>
<tr>
<td>South East Asian Region</td>
<td>53.5</td>
<td>55.4</td>
</tr>
<tr>
<td>Western Pacific Region</td>
<td>63.0</td>
<td>61.8</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>59.7</td>
<td>60.3</td>
</tr>
<tr>
<td>High income countries</td>
<td>70.0</td>
<td><strong>69.7</strong></td>
</tr>
<tr>
<td>African Region</td>
<td>43.8</td>
<td><strong>43.8</strong></td>
</tr>
<tr>
<td>Region of the Americas</td>
<td>67.2</td>
<td>68.0</td>
</tr>
<tr>
<td>Eastern Mediterranean Region</td>
<td>56.1</td>
<td>58.2</td>
</tr>
<tr>
<td>European Region</td>
<td>67.1</td>
<td>67.6</td>
</tr>
<tr>
<td>South East Asian Region</td>
<td>55.0</td>
<td>57.2</td>
</tr>
<tr>
<td>Western Pacific Region</td>
<td>66.7</td>
<td>65.7</td>
</tr>
</tbody>
</table>
References


Conclusions

The results show that

the HALE estimates from WHO are very close to those obtained by the suggested models and methodologies.

Even more, as the new methods are based only on the information included in the mortality expression $m_x$, are extremely useful not only because of their simplicity but also

for the ability to have HALE estimates in all the historical periods as far as life table data exist.
The methods and the models used estimate quite well the healthy life years lost (HLYL) to severe and moderate disability and consequently the healthy life expectancy (HLE) as

$$\text{HLE} = \text{LE} - \text{HLYL}$$

The estimation of the healthy life years lost to light disability is another interesting problem.

We will present our results in a future meeting.

THANK YOU!