Estimated impact on life expectancy and mortality inequality of reducing under-five, maternal, tuberculosis and HIV mortality to a level comparable with four well-preforming countries (China, Chile, Costa Rica and Cuba)

Background paper for The Lancet Commission on Investing in Health (CIH)

Ole F. Norheim, Department for Global Public Health and Primary Care, University of Bergen, Norway, ole.norheim@igs.uib.no

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Summary

Background: The Lancet Commission on Investing in Health will recommend investing in interventions for low- and middle income countries that will reduce under-five, maternal, tuberculosis and HIV mortality to a level comparable with four well-preforming countries (China, Chile, Costa Rica and Cuba – 4C's).

Aim: To estimate how accelerated financing and scale up of four intervention scenarios will impact on life expectancy and inequality in mortality:

- *Scenario 1:* Reduce under-five mortality to the same level as in the 4C's.
- *Scenario 2:* Reduce tuberculosis mortality to the same level as in the 4C's.
- *Scenario 3:* Reduce HIV mortality to the same level as in the 4C's.
- *Scenario 4:* Reduce maternal mortality to the same level as in the 4C's.

Methods: To estimate impact of the four scenarios on life expectancy at birth and mortality inequality, we use standard period life table methods. Changes in inequality in mortality within each region is estimated by Gini applied to health ($Gini_h$ takes the values 0 for perfect equality and 1 for complete inequality).

Results: The number of years of life expectancy gained if under-five mortality is reduced to the level of the 4C' are substantial, especially for low-income countries (6.7 years) and lower middle-income countries (3.6 years). For TB and HIV the largest differences (0.6 and 1.4 years) are seen in low-income countries. Female life expectancy gained due to reduced maternal mortality is 0.5 years in low-income countries. Inequality in mortality ($Gini_h$) for the 4C's is 0.11, and for the low-income countries $Gini_h$ at baseline is much higher ($Gini_h$ = 0.26). For scenario 1 the reduction in inequality is substantial, especially for low-income countries ($Gini_h$ = 0.26 → 0.17) and lower middle-income countries ($Gini_h$ = 0.18 → 0.13). The largest changes in $Gini_h$ for TB, HIV and maternal mortality are seen in South Africa.

Conclusion: These estimates suggest that accelerated financing and scale up of all four intervention scenarios would yield a substantial increase in life expectancy and a positive reduction of inequality in mortality.

Introduction

The last decades have seen a remarkable development in health throughout the world, with substantial improvements in life expectancy and quality of life. In Ethiopia, for example, female life expectancy increased from 48.1 in 1990 to 61.8 in 2011. Male life expectancy increased from 43.1 to 59.0 in the same period.[1] Yet HIV, TB, and remains a challenge in many countries and regions, while others maintain high levels of avertable maternal and child mortality.

The Lancet Commission on Investing in Health will recommend investing in interventions for low- and middle income countries that can reduce under-five, maternal, tuberculosis and HIV mortality to a level comparable with mortality in four well-preforming countries (China, Chile, Costa Rica and Cuba – the 4C's) – before the end of 2035. These well-performing upper middle-income countries have a better than average ratio of health spending to life expectancy, they devote 4-7% of their national wealth to health, and they have fairly well-educated populations.[2] Their example can be aspirational while not unrealistic for low- and middle-income countries. It is therefore interesting to estimate how convergence in mortality for some key patient groups would affect summary measures of population health. Such a converge of mortality is possible at a relative low cost and with substantial economic returns.

The aim of this paper is to estimate how accelerated financing and scale up of different intervention scenarios will impact on life expectancy and inequality in mortality:

- *Scenario 1:* Reduce under-five mortality to the same level as in the 4C's.
- *Scenario 2:* Reduce tuberculosis mortality to the same level as in the 4C's.
- *Scenario 3:* Reduce HIV mortality to the same level as in the 4C's.
- *Scenario 4:* Reduce maternal mortality to the same level as in the 4C's.

We compare four scenarios for changing the mortality patterns in four World Bank income regions (see Appendix B), four countries (Ethiopia, Malawi, India, and South Africa) and globally. We use two summary outcome measures of population health: life expectancy at birth and mortality inequality.

Summary outcome measures of population health

Life expectancy at birth: A life table estimates the number of people dying for each sex- and age-group in a cohort with mortality rates used as input. We estimate life expectancy by standard period life table methods, where life expectancy (e_x) at age x is the average remaining lifetime for a person who survives to the beginning of the indicated age interval.[3] Life expectancy is calculated by dividing the total number of person-years lived from age x (T_x) by the number of persons alive at age x (l_x): $e_x = T_x/l_x$. Life expectancy at birth is the average remaining lifetime in years at birth. Life tables are used to calculate years of life expectancy at birth gained in each region and each country for the four scenarios.

Mortality inequality: We estimate mortality inequality from the same standard period life tables as used for life expectancy. We measure inequality changes within each region and each country for the four scenarios. Inequality in mortality can be summarized by any standard measure of inequality; in this study we use Le Grand's method: Gini applied to age at death ($Gini_h$).

Methods

To estimate impact of the four scenarios on life expectancy at birth and mortality inequality, we use the period life table method.[4] The latest available WHO country (2011) and regional (2009) life tables as well as cause of death data (2011) grouped per income region were used.[1]

As input to estimations we specify changes in age specific mortality rate (${}_nM_x$). The age specific mortality rate ${}_nM_x = {}_nD_x/{}_nP_x$, where ${}_nD_x$ is the number of deaths occurring to persons aged n to x+n, and ${}_nP_x$ is the number of persons aged x to x+n alive at the mid-point (a = 0.5) of the period under consideration (except for ${}_0M_1$ where we set a = 0.2).

First, we calculate a reference age specific mortality rate for under-fives (${}_0M_5$) by taking the weighted average from the four well-performing countries (4C's). Second, we replace this calculated age specific mortality rate for under-fives with present ${}_0M_5$ for each region and country. Third, we calculate and replace age specific mortality rates due to tuberculosis and HIV (separately) for all ages above five in all regions and countries. For regions, changes is age specific mortality rates are calculated as:

$${}_nM_{x\,(\text{scenario 2-3})} = {}_nM_{x\,(\text{region})} - {}_nM_{x\,(\text{region})} * (\delta_{(\text{TB/HIV - region})} - \delta_{(\text{TB/HIV- 4C})}),$$

where ${}_nM_{x\,(\text{region})}$ is the age specific mortality rates for the region or country in question and δ is the proportion of deaths due to TB or HIV in the region or in the 4C's. For country-specific proportions of TB, HIV, and maternal deaths, we use reported data from GBD 2010.[5] Changes in age specific mortality rates due to maternal mortality are calculated for age groups 15-49 (females only) as:

$${}_nM_{x\,(\text{scenario 4})} = {}_nM_{x\,(\text{region})} - {}_nM_{x\,(\text{region})} * (\delta_{(\text{MM - region})} - \delta_{(\text{MM- 4C})})$$

We do not include mortality reductions for children here, since they are captured in the under-five mortality reduction. Age specific mortality rates used for low-income countries compared to the 4C's are listed in table 1.

(Table 1 here)

Changes in age specific mortality rates are used to generate new life tables for estimation of life expectancy at birth and inequality in mortality. Years of life expectancy at birth gained for each scenario in each region and country are calculated simply by life expectancy in the new scenario minus life expectancy according to present mortality patterns (2011):

$$\text{Life expectancy gained} = e_{x(\text{scenario 1-4})} - e_{x(2011)}$$

Inequality in mortality within each region and each country was estimated by Le Grand's method: Gini applied to age at death.[6-8] $Gini_h$ can be calculated in different ways.[9] We use the formula:

$$Gini_h = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{|y_i - y_j|}{n^2\mu}$$

where y_i is the age at death for the *i*th person, n is the number of people in the population (100 000 in our life table model), and μ is average health (life expectancy at birth) in the population. We extracted the expected final distribution of people dying in different age groups from the $_nd_x$ column in the life table. $Gini_h$ takes the values 0 for perfect equality and 1 for complete inequality.

Results

Figure 1 shows survival curves derived from life tables for the four scenarios in the low-income region.

(Figure 1 here)

We see from Figure 1, for low-income countries, a substantial shift in survival for all ages, with marked improvements especially in the younger age groups for reduced under-five mortality to the level of 4c's, and for older age groups for scenario 2 and 3 (for further survival curves, see Appendix A). The survival curve for changes in under-five mortality shows the typical pattern of "rectangularization", that is, a pattern often seen when more individuals in the population live longer and changes for younger age groups go in the direction of more equal age at death. A perfectly rectangularized survival curve would imply that everyone in the population live exactly to the same age. Survival curves for reduced maternal mortality in low-income countries are shown in Figure 2.

(Figure 2 here)

Years of life expectancy gained in the four scenarios are given in Table 2.

(Table 2 here)

We see from Table 2 that years of life expectancy gained if under-five mortality is reduced to the level of the 4C' are substantial, especially for low-income countries (6.7 years) and lower middle-income countries (3.6 years). For TB and HIV the largest differences (0.6 and 1.4 years) are seen in low-income countries. Female life expectancy gained due to reduced maternal mortality is 0.5 years in low-income countries. Even in lower middle-income countries, potential gains in life expectancy are significant.

Table 3 shows changes in inequality in age at death ($Gini_h$) within each region and country.

(Table 3 here)

Inequality in mortality ($Gini_h$) for the 4C's is 0.11. For the low-income countries $Gini_h$ at baseline is much higher ($Gini_h$ = 0.26). For scenario 1 the reduction in inequality is substantial, especially for low-income countries ($Gini_h = 0.26 \rightarrow 0.17$) and lower middle-income countries ($Gini_h = 0.18 \rightarrow 0.13$). The largest changes in $Gini_h$ for TB, HIV and maternal mortality are seen in South Africa.

Discussion

Our estimates show that all scenarios will increase life expectancy and reduce inequality in mortality. The most substantial change is seen for reduced under-five mortality in low-income countries: a change in life expectancy of 6.7 years is indeed remarkable. The 9 % reduction of inequality in mortality is also significant. As noted, these results are estimates, based on years of life expectancy gained when age- and cause-specific mortality patterns for under-five, maternal, tuberculosis and HIV mortality are reduced to the level of four well-preforming countries (4C's). Whether this convergence in mortality will actually translate into health gains remains to be seen.

Some limitations to this study should be noted. Our use of life table models is perhaps the most crude and simple way to estimate population change over time. We used a cohort life table model with age specific mortality rates for 2011 based on certain simplifying assumptions: no attention to changes in fertility and population growth (may affect the measure of inequality), no adjustment for changes in the age composition of the population, fixed background mortality (will change in the period), ignored changes in years lived with disability (changes in mortality do not capture changes in morbidity). Although these are admittedly crude methods, they convey a "birds-eye" view on population change with outcomes presented in easily understood summary measures. Life expectancy at birth has for more than a century been used as a summary measure of population health. Life tables represent patterns of mortality. Although life expectancy is an unobserved measure of a hypothetical cohort with age- and sex-specific mortality patterns, it has proven useful for monitoring the health of populations over time. Since life expectancy is calculated by dividing the total number of person-years lived in a population from age n by the number of persons alive at age x+n it is a precise measure of average health in a population – measured in life years.

Estimates for TB, HIV and maternal deaths are based on regional cause of death tables. Since regional data are not representative for each country, the results for countries, and South Africa in particular, should be treated with special caution.

One limitation with life expectancy is that it is a measure of average health and it ignores distribution of age-at-death in a population. Governments and policy makers are also concerned about the distribution of health. Two populations with the same mean can have different distributions of life years.[10] A summary measure of inequality in age-at-death can be derived from exactly the same data as life expectancy. The $Gini_h$ as a measure of inequality in age-at-death, derived from the ${}_nd_x$ column in life tables, was first suggested and applied by Le Grand, later applied and discussed by several others.[7, 11-13] The Gini is more commonly used as a measure of income inequality in the economic and social sciences.[14] Typical egalitarian societies such as Sweden and Norway have income Gini coefficients around 0.25. Colombia, known for high income inequality, has a Gini of more than 0.50.[13] Since many countries also have significant life-span inequality – some die at birth or before age one, some die at ages over 100 years – Gini can also be used as a population summary measure of inequality in age-at-death. Gini applied to health has not been widely adopted as a population summary measure of health inequality; probably because $Gini_h$ lacks an intuitive interpretation. The $Gini_h$ is a bounded relative measure of inequality, ranging from 0.0 to 1.0. Even if it is easy to explain that a value of, say 0.30, indicates some inequality, and a value of 0.10 less inequality, the significance of this change is difficult to understand and interpret for policy makers. However – as noted by Tony Atkinson, a internationally renowned expert on income inequality – relative $Gini_h$ can easily be transformed to an absolute measure of inequality, and this measure lends itself to an intuitive interpretation.[15] Absolute length of life inequality equals twice average health multiplied with relative $Gini_h$. Absolute length of life inequality can be interpreted as the average deviation in length of life between two randomly picked individuals in a population, measured in life years. The change in $Gini_h$ for low-income countries (0.26 → 0.17) represents a change in absolute inequality from 29.7 years to 22.1 years. This inequality reduction of 7.6 years within the region is significant.

This study does not estimate the cost of scaling up interventions to reduce under-five, maternal, tuberculosis and HIV mortality; these results are described elsewhere. There may also be technological limits to mortality reduction for some interventions, e.g. tuberculosis, in this period.

Conclusion

Accelerated financing and scale up of four intervention scenarios so that under-five, maternal, tuberculosis and HIV mortality converge to the level of the four well-preforming countries (China, Chile, Costa Rica and Cuba) can have a substantial impact on life expectancy and inequality in mortality. The changes are, as expected, greatest for the regions and countries with highest mortality at the baseline. Reduction of under-five mortality to the same level as the 4C's would give the highest positive improvement in life expectancy at birth and inequality in mortality.

Table 1 Input data for estimation of impact on life expectancy and mortality inequality (example for low-income countries)

Age groups	*nMx (4C)*	*nMx (LIC)*	*nMx (scenario 1)*	*nMx (scenario 2)*§	*nMx (scenario 3)*§	*nMx female (scenario 4)*§
0-1	0.00998	0.07975	0.00998	0.07975	0.07975	0.07368
1-4	0.00044	0.01172	0.00044	0.01172	0.01172	0.01161
5-9	0.00024	0.00248	0.00248	0.00248	0.00222	0.00249
10-14	0.00025	0.00160	0.00160	0.00160	0.00143	0.00167
15-19	0.00055	0.00206	0.00206	0.00202	0.00181	0.00197
20-24	0.00078	0.00327	0.00327	0.00322	0.00289	0.00291
25-29	0.00083	0.00438	0.00438	0.00431	0.00398	0.00409
30-34	0.00101	0.00584	0.00584	0.00552	0.00451	0.00565
35-39	0.00131	0.00721	0.00721	0.00682	0.00549	0.00631
40-44	0.00187	0.00856	0.00856	0.00809	0.00637	0.00706
45-49	0.00293	0.01018	0.01018	0.00961	0.00750	0.00819
50-54	0.00452	0.01342	0.01342	0.01248	0.01299	0.01151
55-59	0.00725	0.01912	0.01912	0.01778	0.01842	0.01624
60-64	0.01122	0.02638	0.02638	0.02452	0.02539	0.02229
65-69	0.01813	0.03894	0.03894	0.03621	0.03745	0.03386
70-74	0.02892	0.05971	0.05971	0.05760	0.05965	0.05325
75-79	0.04816	0.09061	0.09061	0.08729	0.09050	0.08270
80-84	0.08370	0.13756	0.13756	0.13226	0.13739	0.12791
85-89	0.13942	0.20331	0.20331	0.19548	0.20306	0.19237
90-94	0.22247	0.29210	0.29210	0.28085	0.29173	0.28126
95-99	0.34052	0.40139	0.40139	0.38593	0.40089	0.39307
100+	0.49971	0.53527	0.53527	0.51466	0.53460	0.53243

* Source for calculations: WHO Life Tables 2011.[1] § Source for calculating proportion TB, HIV, and maternal deaths: GBD 2010.[5]

Table 2 Years of life expectancy gained in the four scenarios

	Total difference from 4C	**Years of life expectancy gained from reduced**			
		Under-5 mortality	TB mortality	HIV/AIDS mortality	Maternal mortality§
Low-income countries	19.5	6.7	0.6	1.4	0.5
- Ethiopia	16.5	4.2	0.4	2.1	0.6
- Rwanda	17.3	2.6	0.4	2.4	0.7
Lower middle-income countries	9.9	3.6	0.3	0.3	0.2
- India	11.4	3.4	0.4	0.1	0.2
Upper middle-income countries	5.8	0.8	0.0	0.4	0.0
- South Africa	18.6	2.1	0.5	3.0	0.9
Global	9.0	3.8	0.2	0.5	0.2

§ LE changes for females only

Table 3 Inequality in age at death ($Gini_h$) within four regions and four countries if mortality are reduced to the level of the 4C's

	Inequality in age at death ($Gini_h$)				
	Baseline	Under-5 mortality	TB	HIV	Maternal mortality
4C's	0.11				
Low-income countries	0.26	0.17	0.26	0.25	0.25
- Ethiopia	0.23	0.18	0.23	0.22	0.22
- Rwanda	0.23	0.20	0.23	0.21	0.22
Lower middle-income countries	0.18	0.13	0.18	0.17	0.17
- India	0.18	0.14	0.18	0.18	0.17
Upper middle-income countries	0.14	0.14	0.14	0.14	0.12
- South Africa	0.23	0.20	0.23	0.21	0.18
Global	0.22	0.14	0.18	0.18	0.18

Figure 1 Survival curves for Scenario 1-3 for low-income countries

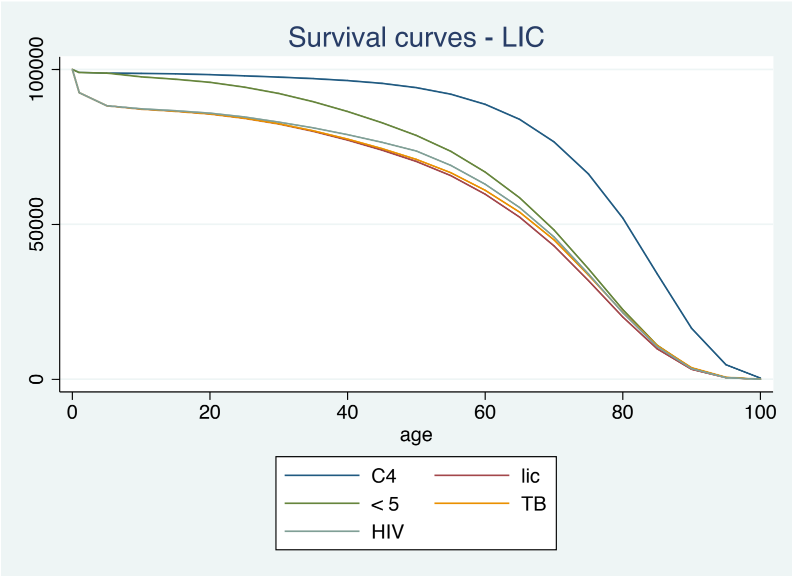
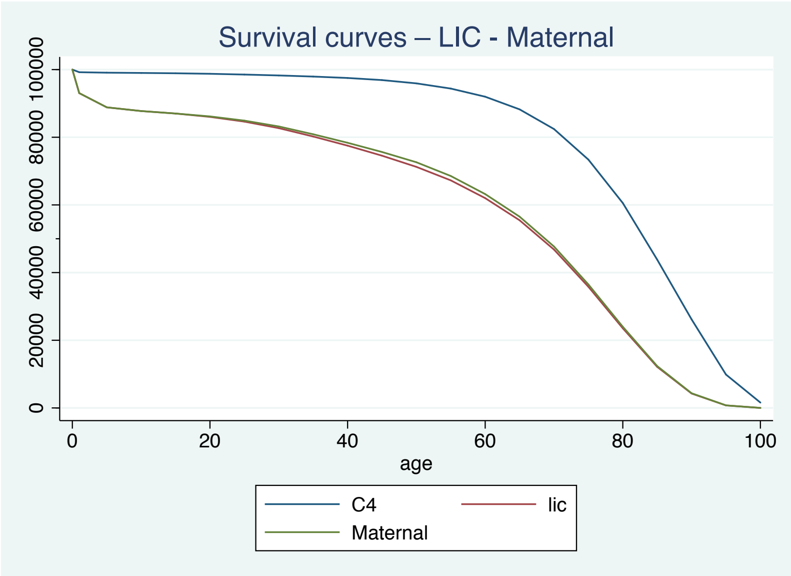
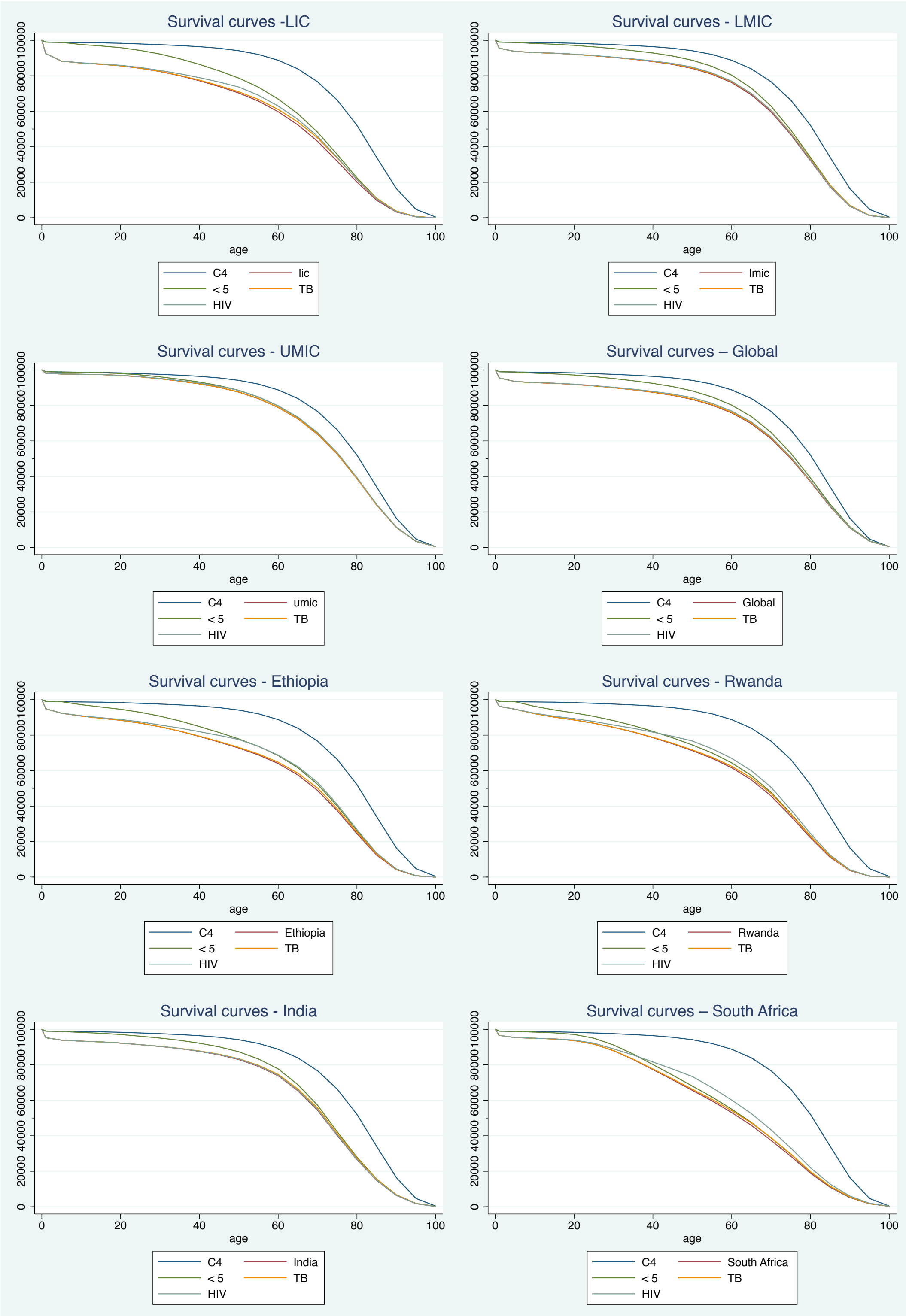


Figure 2 Survival curves for Scenario 4, low-income countries

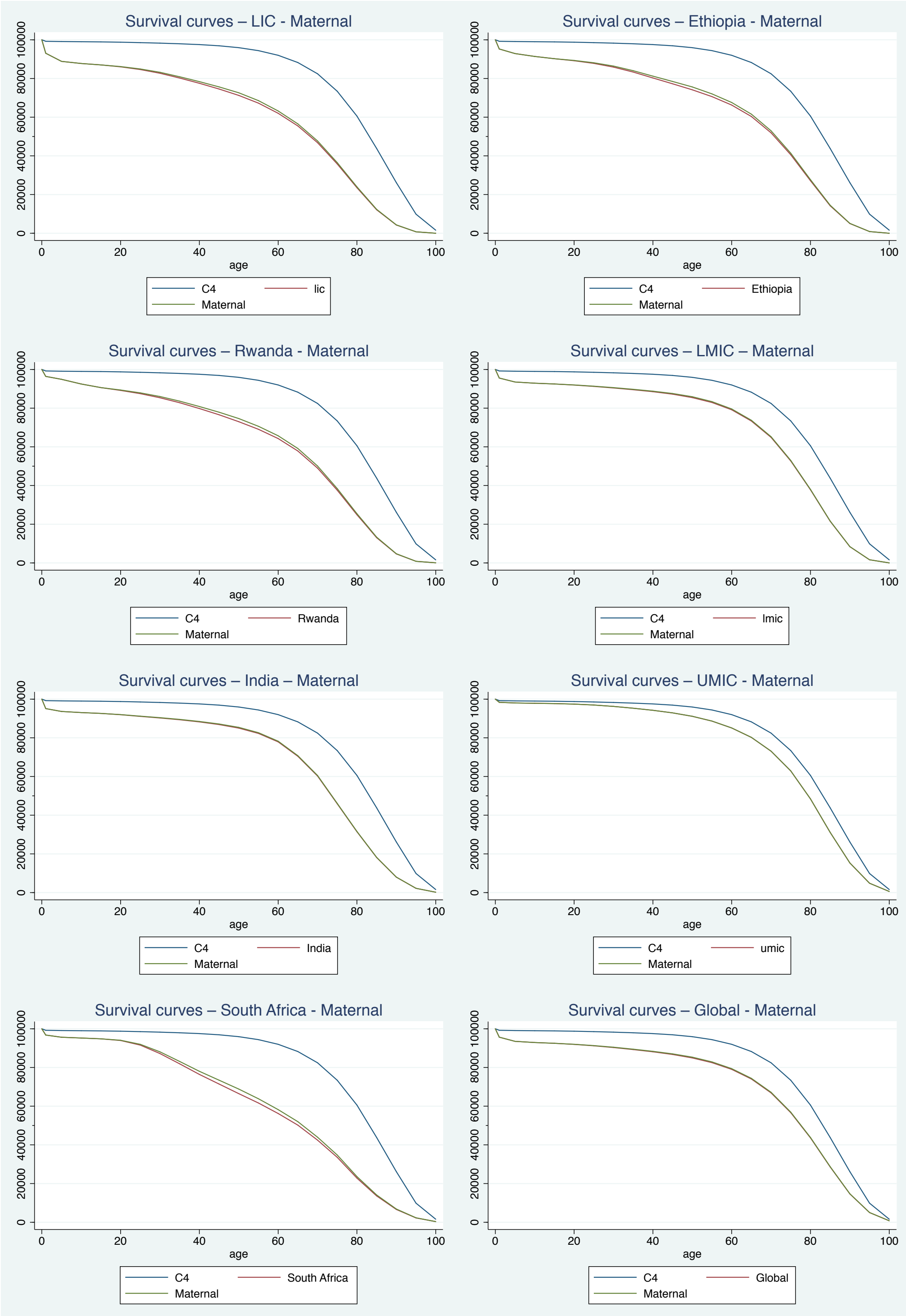


Appendix A.

Survival curves for Scenario 1-3 in four World Bank regions and four countries



Survival curves (females) for Scenario 4 in four World Bank regions and four countries



Appendix B. List of countries in World Bank Regions

Countries are classified according to the World Bank income and geographic regional categories for the year 2011 (World Bank list of economies, July 2012).

Low income countries: Afghanistan; Bangladesh; Benin; Burkina Faso; Burundi; Cambodia; Central African Republic; Chad; Comoros; Democratic People's Republic of Korea; Democratic Republic of the Congo; Eritrea; Ethiopia; Gambia; Guinea; Guinea; Bissau; Haiti; Kenya; Kyrgyzstan; Liberia; Madagascar; Malawi; Mali; Mauritania; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sierra Leone; Somalia; Tajikistan; Togo; Uganda; United Republic of Tanzania; and Zimbabwe.

Lower middle income countries: Albania; Armenia; Belize; Bhutan; Bolivia (Plurinational State of); Cameroon; Cape Verde; Congo; Côte d'Ivoire; Djibouti; Egypt; El Salvador; Fiji; Georgia; Ghana; Guatemala; Guyana; Honduras; India; Indonesia; Iraq; Kiribati; Lao People's Democratic Republic; Lesotho; Marshall Islands; Micronesia (Federated States of); Mongolia; Morocco; Nicaragua; Nigeria; Pakistan; Papua New Guinea; Paraguay; Philippines; Republic of Moldova; Samoa; Sao Tome and Principe; Senegal; Solomon Islands; South Sudan; Sri Lanka; Sudan; Swaziland; Syrian Arab Republic; Timor; Leste; Tonga; Ukraine; Uzbekistan; Vanuatu; Viet Nam; Yemen; and Zambia

Upper middle income countries: Algeria; Angola; Antigua and Barbuda; Argentina; Azerbaijan; Belarus; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; Chile; China; Colombia; Cook Islands; Costa Rica; Cuba; Dominica; Dominican Republic; Ecuador; Equatorial Guinea; Gabon; Grenada; Iran (Islamic Republic of); Jamaica; Jordan; Kazakhstan; Latvia; Lebanon; Libya; Lithuania; Malaysia; Maldives; Mauritius; Mexico; Montenegro; Namibia; Nauru; Niue; Palau; Panama; Peru; Romania; Russian Federation; Saint Lucia; Saint Vincent and the Grenadines; Serbia; Seychelles; South Africa; Suriname; Thailand; The former Yugoslav Republic of Macedonia; Tunisia; Turkey; Turkmenistan; Tuvalu; Uruguay; and Venezuela (Bolivarian Republic of)

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