Worldwide mortality in men and women aged 15–59 years from 1970 to 2010: a systematic analysis

Julie Knoll Rajaratnam, Jake R Marcus, Alison Levin-Rector, Andrew N Chalupka, Haidong Wang, Laura Dwyer, Megan Costa, Alan D Lopez, Christopher J L Murray

Summary

Background Adult deaths are a crucial priority for global health. Causes of adult death are important components of Millennium Development Goals 5 and 6. However, adult mortality has received little policy attention, resources, or monitoring efforts. This study aimed to estimate worldwide mortality in men and women aged 15–59 years.

Methods We compiled a database of 3889 measurements of adult mortality for 187 countries from 1970 to 2010 using vital registration data and census and survey data for deaths in the household corrected for completeness, and sibling history data from surveys corrected for survival bias. We used Gaussian process regression to generate yearly estimates of the probability of death between the ages of 15 years and 60 years (45q15) for men and women for every country with uncertainty intervals that indicate sampling and non-sampling error. We showed that these analytical methods have good predictive validity for countries with missing data.

Findings Adult mortality varied substantially across countries and over time. In 2010, the countries with the lowest risk of mortality for men and women are Iceland and Cyprus, respectively. In Iceland, male 45q15 is 65 (uncertainty interval 61–69) per 1000; in Cyprus, female 45q15 is 38 (36–41) per 1000. Highest risk of mortality in 2010 is seen in Swaziland for men (45q15 of 765 [692–845] per 1000) and Zambia for women (606 [518–708] per 1000). Between 1970 and 2010, substantial increases in adult mortality occurred in sub-Saharan Africa because of the HIV epidemic and in countries in or related to the former Soviet Union. Other regional trends were also seen, such as stagnation in the decline of adult mortality for large countries in southeast Asia and a striking decline in female mortality in south Asia.

Interpretation The prevention of premature adult death is just as important for global health policy as the improvement of child survival. Routine monitoring of adult mortality should be given much greater emphasis.

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Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA, USA (J K Rajaratnam PhD, J R Marcus BA, A Levin-Rector BSPH, H Wang PhD, L Dwyer BA, M Costa BA, Prof C J L Murray MD); **Harvard Medical School, Harvard University, Boston, MA, USA** (A N Chalupka); **and School of Population Health, University of Queensland, Brisbane, QLD, Australia** (Prof A D Lopez PhD)

Correspondence to:
Prof Christopher J L Murray,
Institute for Health Metrics and
Evaluation, University of
Washington, 2301 5th Avenue,
Suite 600, Seattle, WA 98121,
USA
cjlm@u.washington.edu

Introduction

Public health efforts in the 1980s and 1990s had a substantial focus on improving mortality and morbidity in children.[1–3] Both the numbers and rates of death in children under 5 years of age have been falling for several decades, although many countries are not on track to achieve Millennium Development Goal (MDG) 4, which calls for a two-thirds reduction in the mortality rate in children younger than 5 years between 1990 and 2015.[1,3–6] Concomitant with decreases in under-5 mortality, global fertility has declined from a total fertility rate (TFR) of 5·0 in 1950 to 2·5 in 2009, leading to a substantial increase in the mean and median age of most populations.[7] Declining under-5 mortality rates and ageing populations also mean that a larger proportion of deaths occur in adults.[7,8] Despite the increase in adult population and the related change in population health issues that follow this demographic shift, there has been much less global health focus on the health and survival of adults.

In 1992, Feachem and colleagues[9] drew attention to deaths in adults aged 15–59 years. Deaths in individuals aged younger than 60 years can be considered premature by any standard.[10–12] Deaths in the most economically and socially active groups can also have major effects on society.[13–15] For these reasons, the World Bank and subsequently WHO have reported adult mortality risk, also referred to as 45q15.[8,16] For a given year, 45q15 represents the probability that an individual who has just turned 15 years will die before reaching the age of 60 years, on the assumption that the age-specific mortality conditions of the year are constant throughout this individual's life.

Interest in adult mortality has been intensified through the Millennium Declaration. MDG 5 on maternal health focuses on one of the important causes of death in women aged 15–49 years. Adult female mortality rates are an essential component of the measurement of the maternal mortality ratio.[17] Two of the three diseases covered by MDG 6, tuberculosis and HIV, are largely killers of adults—95% and 85% of deaths from these diseases, respectively, occur in people older than 15 years.[8] Although maternal mortality, HIV, and tuberculosis have received substantial policy attention and development assistance for health,[18] the rising burden of non-communicable diseases in developing countries has received much less policy attention.[19–21]

Despite the attention on specific diseases that affect adults, policy traction towards improving overall adult

health outcomes continues to be low.[9] This disinterest has led to widespread neglect for building and maintaining data systems for measuring adult mortality.[22,23] Tracking change in this basic outcome of adult health is important for assessing progress, improving interventions, and driving further investment.[24] However, challenges in measurement of adult mortality have been noted historically and continue to persist.[2,22,23,25,26]

Assessments every 2 years by the United Nations Population Division (UNPD) are undertaken to produce population estimates and projections for most countries for 5-year periods. These efforts also produce estimates of life expectancy, age-specific deaths, and 45q15, but for most developing countries, the estimates are based on models that assume a close correlation between adult and under-5 mortality.[7] WHO also periodically produces estimates of 45q15; these often differ substantially from UNPD estimates. WHO does not produce a complete time series (only selected years) and, similar to UNPD, major limitations of WHO's approach are that the process is neither transparent nor replicable.[27] Large-scale systematic assessments that cover all publicly available data sources over several decades have been completed for children but not for adults.[1,28,29] In countries without complete vital registration systems, there has been disagreement about the best methods to analyse and interpret partial vital registration data, survey data for sibling histories, and survey or census recall of deaths.[2] For some regions, important comparative analyses of available data have been undertaken but these efforts did not cover the entire developing and developed world.[30] The absence of a systematic assessment of the evidence on trends in adult mortality, especially in developing countries, has resulted in a "scandal of ignorance".[2,30,31] Several developments in data availability and analytical methods now make a systematic assessment of trends in 45q15 feasible. Improved methods for analysis of incomplete vital registration or sample registration data are now available.[32] Issues of survivor bias in the analysis of sibling histories widely available in sub-Saharan Africa have been addressed and practical implementation of this approach worked out.[33,34] More demographic surveillance system and sample registration data are available.[35] Finally, techniques used to synthesise multiple data sources for children can be adapted for studying adult mortality (Rajaratnam J K, et al, unpublished data). In this study, we systematically analysed data for 187 countries from 1970 to 2010 to estimate 45q15 for men and women.

Methods

Data sources

Empirical measurements of adult mortality were drawn from four types of sources (table 1): (1) vital registration data, (2) sample registration systems (when available), and nationally representative survey or census data that enable direct estimation of age-specific adult mortality

|	Empirical measurements	Outliers
Vital registration[36–41]	3489	114
Sample registration systems[42–46]	61	3
Household deaths		
Demographic and Health surveys[47]	10	2
Pan Arab Project for Child Development surveys[48–56]	9	0
Censuses[38]	25	4
Country-specific surveys[57–63]	14	2
Sibling histories		
Demographic and Health surveys[47]	179	1
Pan Arab Project for Family Health surveys[64]	3	3
CDC reproductive health surveys[65]	19	0
Country-specific surveys[61,66]	6	0
Demographic surveillance sites: Bangladesh, Papua New Guinea, Vietnam[67]	47	17
Disease surveillance points: China[68]	10	0
Other[38, 69–73]	17	3
Total	3889	149

CDC=Centers for Disease Control and Prevention. Outliers are points excluded from analysis after country-by-country review of all data.

Table 1: **Data sources for empirical measurements of adult mortality**

rates from questions about either (3) deaths in the household or (4) the survival of siblings of a respondent. In a few cases, an estimate of 45q15 from survey reports was used when other sources of microdata or tabulated data were not obtainable for direct analysis. For three countries (Bangladesh, Vietnam, and Papua New Guinea), we included mortality estimates from demographic surveillance sites. For China, we included data from the disease surveillance points system[68] to supplement the few nationally representative data sources available.

We assessed, by use of the most effective methods, the level of completeness of reporting of deaths in vital registration systems, sample registration systems, and household sources relative to completeness of census coverage.[32] If several assessments of completeness for each of these sources were available, we combined the results to create a time series of completeness as described in webappendix pp 9–12. For vital registration and sample registration systems, if the rate of death reporting was lower than 95% (we assumed that it was not possible for these systems to over-register deaths), age-specific estimates of death rates were adjusted upward by the inverse of the estimated level of completeness. For survey data for deaths in the household, estimates of age-specific death rates were adjusted either up or down on the basis of the inverse of the estimated level of completeness, because "telescoping", or including deaths from outside the recall period, can lead to overestimation of death rates.[74,75] Age-specific population estimates[7,36] were used to compute death rates for vital registration and census

See **Online** for webappendix
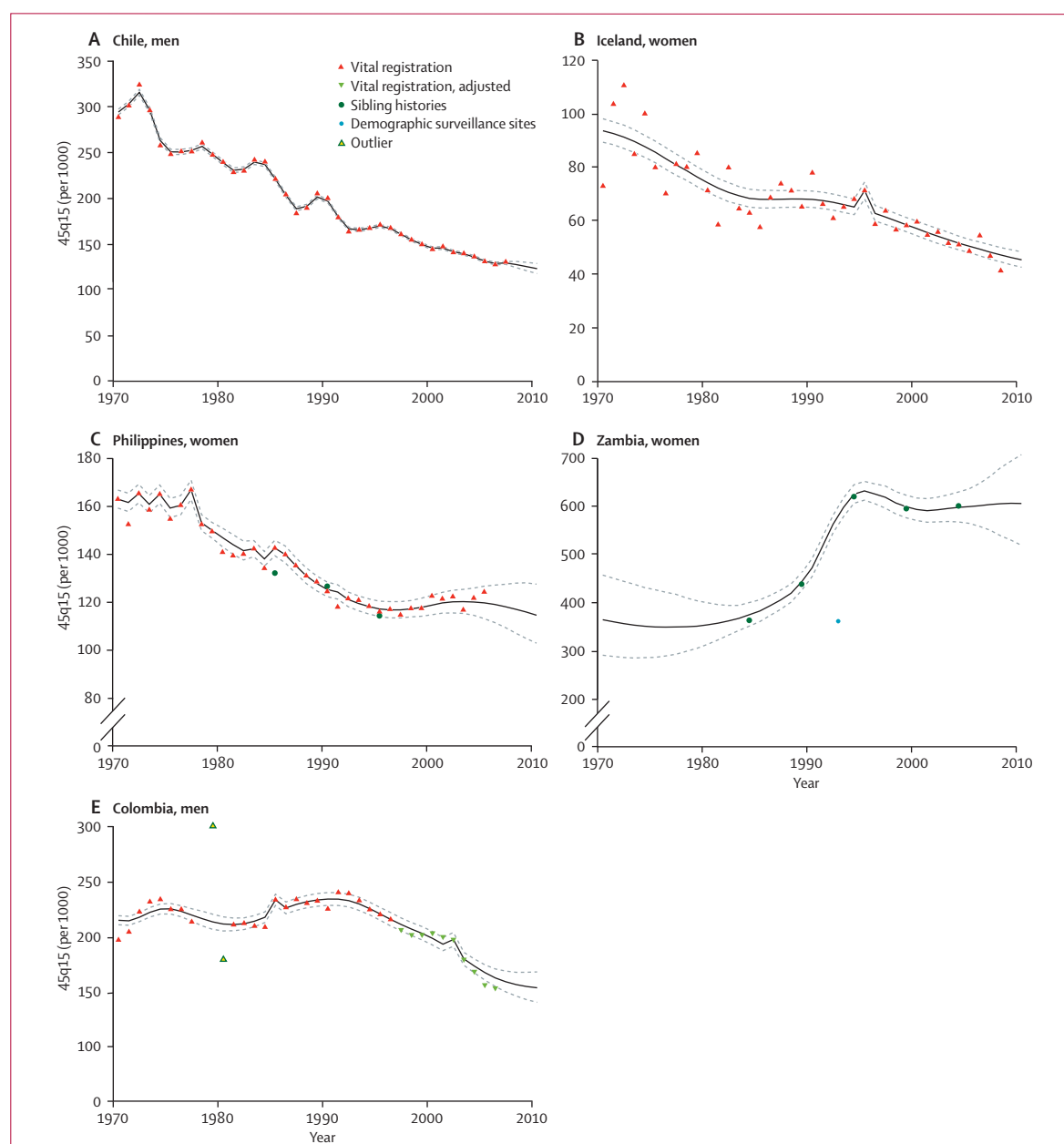
Figure 1: **45q15 from 1970 to 2010 in selected countries**
Dashed lines indicate uncertainty intervals. See text for definition of 45q15.

household deaths. The population for Cyprus does not include the Turkish Cypriot population that is not captured in the vital registration data. Singapore vital registration data capture deaths of legal residents, but not deaths of migrant workers or their families. Denominators for other sources, such as sample registration systems and survey household deaths that represented samples of the total population, were obtained directly from those sources.

Microdata from surveys containing information about survival of siblings were analysed by use of the methods described by Obermeyer and colleagues[34] that correct for survival and recall bias in this type of survey. All Demographic and Health Surveys (DHS) were pooled together as the analytic method required. Sibling survival data from other sources (eg, US Centers for Disease Control and Prevention reproductive health surveys, Pan Arab Project for Family Health surveys) were pooled with DHS to establish reliable age patterns of mortality, but only results from the additional surveys (non-DHS) were retained from these analyses.

The total number of empirical measurements of 45q15 across all data sources was 3889; measurements for men and women from the same source were counted only once (table 1) and this amount included only data in the estimation period (1970–2010). If available, we included measurements in our empirical database back to 1950. Every data point from a sibling history survey covered a 5-year period, and so therefore covered five times the number of years than did datapoints from vital registration or sample registration systems. After country-by-country review of the empirical datapoints, 149 points were deemed to be outliers and therefore excluded from the analysis. These outliers are marked on the national plots of data and estimates in webappendix pp 18–391.

Webappendix p 392 shows the availability of empirical measurements by major UN region. Most directly observed data for adult mortality come from North America, Europe, and Latin America and the Caribbean. Data availability for Africa and Asia is poor for the 1970s but increases; 60% or more countries within these regions are represented between 1985 and the early 2000s. This increase is largely because of the availability of sibling history data from DHS in these regions. Oceania remains a region with limited data availability over the time period of estimation. In all regions, there is a time gap between collection and public release of data; this gap is greatest for Africa, but still evident even for North America, where the latest data for Canada are for 2006. Despite our efforts to identify data sources, data for 1970–2010 were unavailable for 12 countries. Our estimation methods had to therefore forecast (and in many cases reverse-forecast) to cover the entire period of 1970–2010 for all countries; all estimates for 2010 are forecasts.

The estimation process described below to synthesise all of the empirical measurements of adult mortality makes use of time series estimates of covariates related to adult mortality, including estimates of mortality in children younger than 5 years of age, estimates of HIV seroprevalence from UNAIDS, and a lagged distributed income series based on a triangular weighted mean of the past 10 years' gross domestic product per head in international dollars (data from Institute for Health Metrics and Evaluation gross domestic product time series dataset, March 2010 version).[76] Finally, we compiled data for war-related deaths from the Uppsala Conflict Data Program[77–79] and deaths caused by natural disasters from the Centre for Research on the Epidemiology of Disasters[80] to generate a war/disaster rate for each country over time that we used to model rates of mortality from war and natural disasters.

Statistical analysis

For each country, we generated a time series of 45q15 estimates by synthesising the empirical data estimates with an analytical technique called Gaussian process regression. This technique estimates the probability that a function describes the data well. Details
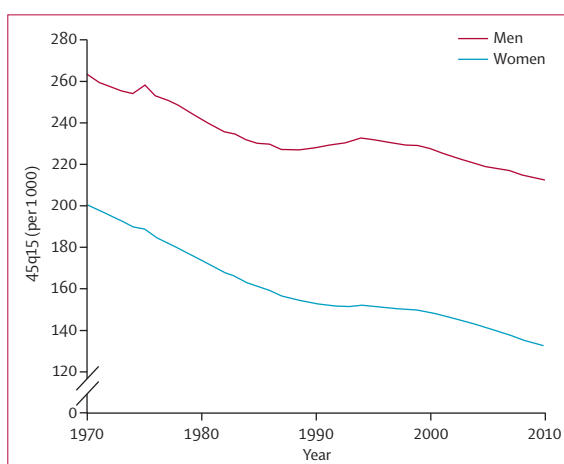
Figure 2: **Worldwide 45q15 in men and women from 1970 to 2010**
See text for definition of 45q15.

of the implementation of this technique are shown in webappendix pp 1–17.

Briefly, we applied models relating rates and trends of under-5 mortality, HIV seroprevalence, and lagged distributed income with adult mortality, and harnessed spatial and time correlation between adult mortality observations for countries within the same region, to establish a predicted time series of adult mortality in each country. This predicted series was then updated by the data for each country by Gaussian process regression. The benefit of this approach is that we allowed the estimation process to be data-driven and to borrow strength from other time periods and neighbouring countries when direct measurements of adult mortality were not available for a given period in a particular country. Gaussian process regression takes into account the uncertainty around each empirical measurement of adult mortality and accordingly smoothes data that are noisy (ie, with large variation because of sampling or small numbers) and uncertain. For countries with reliable data, the Gaussian process regression estimates closely tracked the observed data. As described in webappendix pp 12–13, we assessed the validity of this strategy to synthesise data sources by repeatedly undertaking four types of out-of-sample predictive validity tests. When 20% of country-years were excluded from the analysis, the Gaussian process regression predictions for these country-years had a median relative error of 2·8%. When all data for 20% of countries were excluded from the analysis, predictions had a median relative error of 14·0%. Similar results for forecasting and reverse-forecasting were 7·3% and 6·3%, respectively. Predictive validity for countries without vital registration is slightly worse and presented in detail in webappendix p 14.

Time series smoothing models do not handle well the occurrence of mortality shocks—ie, unexpected and striking increases in risk of mortality (and the

subsequent steep declines) caused by natural disasters or war. To account for mortality shocks in our time series estimates, we withheld empirical measurements obtained during war or disaster periods from the Gaussian process regression estimation process. This approach allowed our model to generate a counter-factual estimate of mortality during the shock period to which we added excess mortality caused by the shock.

Excess mortality was calculated by several steps. Shock years were defined as those in which the war/disaster rate was reported to exceed one death per 10 000 population in a year. We developed an empirical model that related change in 45q15 from baseline observed in the empirical datasets to the war/disaster death rate. On the basis of this model, for each shock year we predicted the increase in 45q15. If data for that shock year were available in a country and the 45q15 value was higher than the predicted increase, the observed data were used for the shock. If no data were available, the predicted excess mortality was used (webappendix p 7).

Countries were grouped into 21 regions on the basis of epidemiological profiles and geography (webappendix p 393).[81] For each region, we generated a time series of adult mortality by use of a population (aged 15–59 years) weighted average of all countries within the region. A similar calculation was done to obtain a global time series of 45q15.
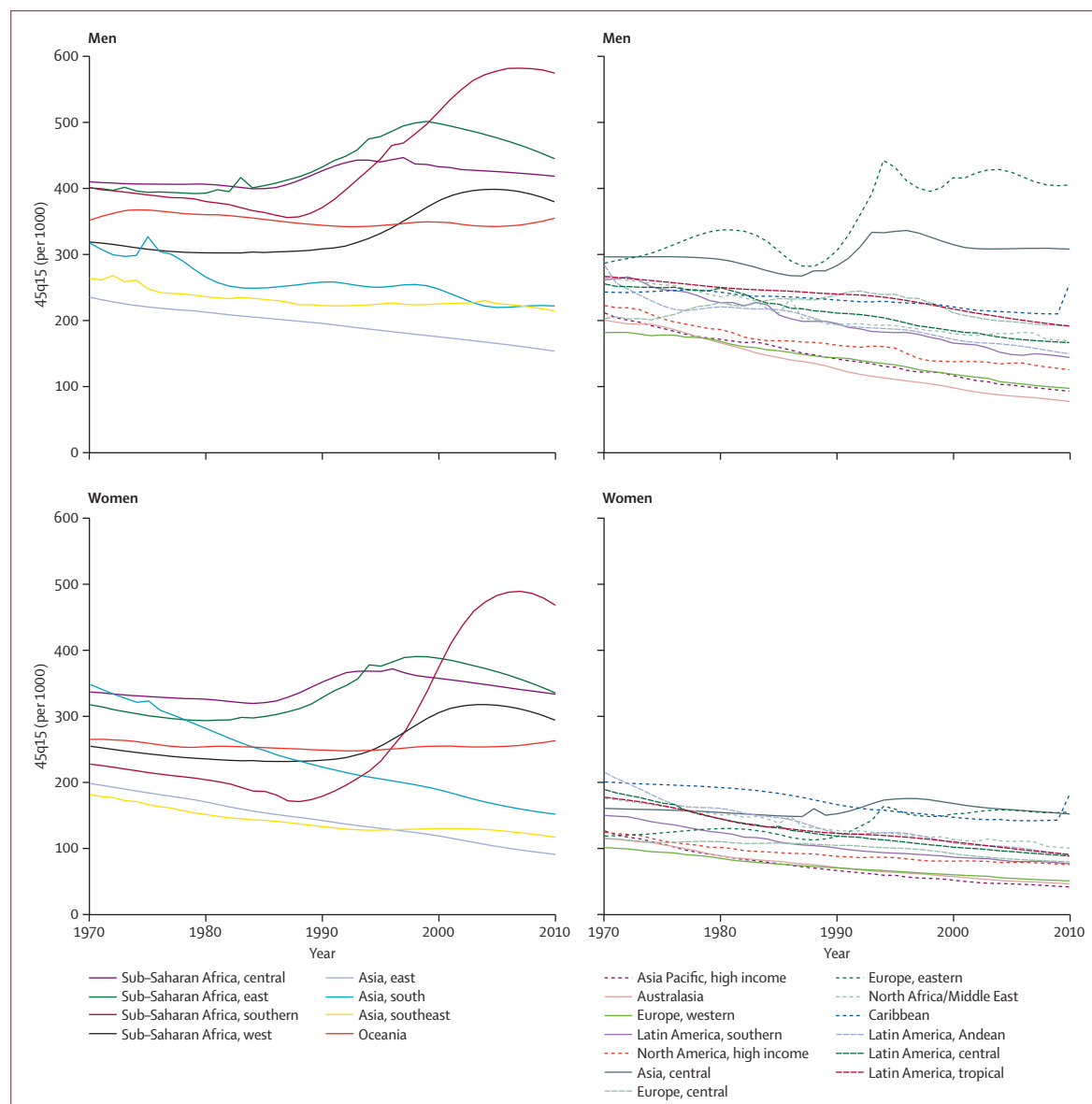
Figure 3: **45q15 from 1970 to 2010, by region**
See text for definition of 45q15.

	1970		1990		2010	
	Women	Men	Women	Men	Women	Men
Asia-Pacific, high income						
Brunei	157 (149–165)	174 (166–182)	119 (113–126)	152 (144–159)	91 (82–100)	116 (106–128)
Japan	103 (102–103)	171 (170–171)	53 (53–54)	109 (108–109)	41 (38–45)	84 (78–90)
Singapore	145 (141–149)	240 (234–245)	85 (83–87)	145 (142–148)	47 (44–51)	87 (81–95)
South Korea	221 (199–244)	379 (345–417)	99 (98–101)	233 (230–237)	40 (38–43)	112 (104–120)
Asia, Central						
Armenia	108 (97–120)	200 (178–225)	99 (97–101)	210 (205–216)	77 (72–82)	209 (193–227)
Azerbaijan	150 (136–165)	280 (250–314)	131 (128–134)	273 (266–280)	105 (97–113)	220 (203–239)
Georgia	134 (119–152)	277 (247–310)	108 (105–112)	252 (245–258)	86 (79–94)	235 (217–255)
Kazakhstan	153 (135–173)	335 (296–379)	141 (137–145)	316 (310–323)	181 (167–195)	440 (408–474)
Kyrgyzstan	168 (148–190)	314 (279–354)	148 (144–152)	288 (281–294)	144 (134–155)	325 (304–348)
Mongolia	257 (230–289)	321 (286–359)	262 (252–272)	356 (344–369)	241 (229–254)	490 (468–512)
Tajikistan	192 (172–215)	263 (234–295)	169 (164–174)	245 (239–252)	151 (140–163)	259 (239–281)
Turkmenistan	197 (179–216)	324 (295–355)	167 (163–170)	284 (278–289)	120 (109–132)	273 (249–301)
Uzbekistan	170 (154–187)	286 (256–319)	175 (171–179)	285 (277–292)	167 (155–179)	283 (260–308)
Asia, east						
China	198 (183–214)	236 (220–254)	142 (137–147)	197 (191–204)	90 (85–97)	155 (144–166)
North Korea	215 (202–230)	300 (285–317)	159 (149–170)	232 (219–245)	141 (130–153)	223 (208–239)
Taiwan	140 (136–144)	219 (213–226)	90 (88–92)	179 (175–183)	59 (56–61)	144 (138–151)
Asia, south						
Afghanistan	398 (326–487)	347 (278–432)	323 (259–402)	299 (238–377)	295 (227–383)	289 (215–389)
Bangladesh	308 (276–344)	306 (247–378)	192 (184–200)	231 (217–245)	121 (106–137)	172 (141–209)
Bhutan	357 (331–384)	335 (312–361)	208 (192–226)	246 (226–267)	129 (113–147)	185 (160–213)
India	358 (347–370)	330 (305–358)	225 (219–231)	266 (256–276)	145 (135–155)	228 (197–265)
Nepal	282 (217–366)	301 (225–403)	212 (190–237)	260 (230–293)	118 (100–138)	179 (149–213)
Pakistan	283 (257–313)	235 (208–265)	226 (209–243)	241 (222–261)	218 (182–260)	241 (192–302)
Asia, southeast						
Burma	250 (231–271)	331 (311–352)	210 (194–228)	318 (299–339)	165 (148–185)	272 (248–298)
Cambodia	209 (178–246)	443 (380–515)	186 (176–197)	363 (346–381)	162 (145–181)	324 (288–364)
Indonesia	175 (147–209)	231 (200–266)	132 (126–138)	196 (188–203)	131 (115–148)	215 (195–237)
Laos	268 (247–290)	343 (319–369)	215 (198–234)	318 (296–342)	167 (149–187)	265 (241–291)
Malaysia	196 (185–208)	255 (244–266)	118 (116–120)	187 (185–189)	82 (73–93)	154 (139–171)
Maldives	349 (296–412)	279 (242–321)	229 (217–241)	212 (201–223)	76 (68–85)	107 (99–117)
Mauritius	199 (192–206)	309 (299–319)	117 (113–122)	255 (247–262)	107 (97–118)	213 (192–236)
Philippines	163 (159–167)	249 (244–254)	125 (122–128)	246 (242–250)	115 (103–128)	225 (211–241)
Seychelles	155 (142–169)	253 (238–270)	117 (109–125)	267 (253–282)	93 (79–110)	258 (232–287)
Sri Lanka	156 (153–158)	211 (208–214)	98 (94–103)	217 (210–224)	68 (57–80)	192 (169–220)
Thailand	190 (186–194)	265 (257–273)	106 (103–108)	198 (192–204)	100 (93–107)	200 (181–221)
Timor-Leste	265 (246–285)	338 (315–363)	197 (183–213)	305 (284–328)	171 (152–191)	275 (250–303)
Vietnam	149 (124–179)	328 (283–381)	121 (104–141)	245 (215–280)	81 (72–92)	201 (180–224)
Australasia						
Australia	113 (112–115)	202 (200–204)	67 (66–68)	124 (122–125)	44 (42–46)	76 (73–78)
New Zealand	116 (114–119)	193 (190–197)	88 (87–90)	142 (140–145)	56 (54–59)	84 (81–87)

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Role of the funding source

Results

The empirical measurements of 45q15 and the results of our data synthesis, including uncertainty intervals, are available for each country in webappendix pp 18–391; five examples of these data plots are shown in figure 1. Data for adult male mortality in Chile provide an example of a complete time series with complete vital registration

	1970		1990		2010	
	Women	Men	Women	Men	Women	Men
(Continued from previous page)						
Caribbean						
Antigua and Barbuda	168 (153–183)	227 (208–247)	102 (93–111)	183 (169–199)	99 (82–120)	193 (162–229)
Barbados	142 (136–148)	200 (190–210)	104 (100–109)	175 (168–183)	82 (73–92)	133 (114–156)
Belize	139 (129–150)	174 (162–188)	115 (106–123)	172 (162–183)	138 (116–164)	226 (193–264)
Cuba	113 (112–115)	144 (142–146)	108 (107–109)	153 (152–155)	79 (75–84)	120 (113–128)
Dominica	170 (154–188)	233 (211–258)	125 (113–138)	189 (171–210)	100 (82–122)	164 (135–200)
Dominican Republic	143 (136–150)	166 (159–174)	103 (98–108)	163 (156–171)	100 (87–115)	180 (157–205)
Grenada	182 (168–198)	250 (233–268)	146 (135–159)	214 (201–228)	133 (113–157)	236 (206–270)
Guyana	218 (209–228)	298 (285–311)	176 (170–183)	306 (295–318)	175 (159–194)	253 (221–290)
Haiti	475 (375–601)	530 (424–661)	411 (393–430)	481 (460–502)	483 (410–569)	585 (505–676)
Jamaica	175 (168–182)	227 (219–236)	125 (99–158)	190 (152–236)	108 (90–131)	193 (163–228)
Saint Lucia	182 (161–204)	244 (222–269)	144 (133–156)	204 (192–216)	103 (85–124)	187 (163–216)
Saint Vincent and the Grenadines	169 (149–191)	235 (211–262)	143 (127–159)	201 (184–219)	132 (110–158)	203 (176–235)
Suriname	226 (207–246)	285 (266–305)	168 (160–177)	255 (245–266)	184 (160–211)	293 (257–335)
The Bahamas	240 (227–253)	357 (340–376)	171 (164–179)	292 (281–304)	142 (127–159)	252 (229–277)
Trinidad and Tobago	199 (194–204)	260 (254–265)	161 (157–165)	241 (236–246)	106 (95–119)	210 (190–231)
Europe, central						
Albania	112 (105–119)	178 (164–192)	76 (74–78)	145 (142–147)	62 (57–66)	126 (117–135)
Bosnia and Herzegovina	146 (136–156)	247 (228–267)	94 (92–97)	199 (195–204)	70 (67–73)	149 (143–156)
Bulgaria	101 (99–103)	164 (161–166)	97 (95–99)	218 (215–220)	87 (83–92)	211 (198–225)
Croatia	130 (120–142)	262 (238–288)	94 (92–96)	234 (230–238)	62 (59–65)	160 (151–168)
Czech Republic	109 (108–111)	222 (220–225)	94 (93–95)	220 (218–223)	63 (61–65)	139 (134–144)
Hungary	114 (112–116)	199 (196–201)	133 (131–135)	304 (301–307)	103 (97–109)	245 (229–261)
Macedonia	121 (112–131)	186 (170–202)	95 (92–98)	169 (165–173)	77 (73–81)	149 (142–156)
Montenegro	154 (143–167)	238 (216–261)	109 (102–117)	200 (185–217)	81 (78–85)	164 (156–173)
Poland	105 (104–106)	206 (204–207)	102 (101–103)	263 (262–265)	78 (74–83)	207 (195–220)
Romania	121 (119–122)	188 (186–190)	114 (112–115)	238 (236–240)	91 (86–96)	217 (204–232)
Serbia	127 (117–138)	195 (179–213)	96 (91–102)	177 (166–188)	70 (68–73)	145 (140–150)
Slovakia	109 (107–111)	214 (211–218)	102 (100–104)	268 (265–272)	74 (70–78)	191 (180–204)
Slovenia	140 (130–150)	287 (263–314)	91 (89–93)	222 (218–227)	56 (53–59)	138 (129–146)
Europe, eastern						
Belarus	115 (111–119)	255 (246–264)	116 (112–120)	300 (292–309)	132 (122–142)	378 (347–411)
Estonia	104 (101–107)	256 (250–262)	110 (107–113)	297 (291–303)	87 (81–93)	253 (235–272)
Latvia	113 (110–116)	262 (257–268)	117 (114–120)	308 (302–314)	121 (112–130)	325 (299–354)
Lithuania	105 (103–108)	247 (242–252)	108 (106–111)	289 (284–294)	115 (108–122)	316 (295–338)
Moldova	181 (165–200)	297 (265–334)	157 (154–160)	281 (276–287)	140 (132–150)	310 (290–333)
Russia	121 (118–123)	308 (302–315)	118 (116–120)	316 (310–322)	157 (147–167)	412 (383–442)
Ukraine	108 (105–111)	240 (234–246)	113 (111–116)	286 (280–292)	157 (146–169)	422 (388–458)
Europe, western						
Andorra	76 (71–81)	145 (137–154)	64 (60–68)	125 (117–132)	49 (45–52)	96 (90–103)
Austria	107 (105–109)	206 (203–208)	74 (72–75)	156 (154–159)	48 (46–51)	98 (93–103)
Belgium	105 (103–107)	194 (192–197)	76 (74–77)	140 (138–142)	60 (57–63)	104 (99–110)
Cyprus	97 (90–104)	151 (142–161)	58 (55–60)	109 (105–112)	38 (36–41)	85 (80–90)
Denmark	104 (102–106)	158 (155–160)	98 (97–100)	151 (149–153)	65 (62–68)	108 (103–114)
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data. In this case, our Gaussian process regression model produced estimates that were very close to the observed data and the uncertainty intervals represent only the sampling uncertainty in the death rates at each age. Iceland also had a complete vital registration system

but because of small population size, 45q15 for women fluctuated from year to year. The model, taking into account this sampling variance, produced a smooth time trend that followed the empirical data, and, because of the degree of sampling error, uncertainty intervals for

	1970		1990		2010	
	Women	Men	Women	Men	Women	Men
(Continued from previous page)						
Finland	101 (99–103)	259 (255–263)	70 (68–72)	182 (179–184)	54 (51–57)	124 (118–130)
France	98 (97–99)	199 (198–200)	67 (66–67)	162 (161–163)	53 (50–56)	116 (110–122)
Germany	109 (108–110)	192 (191–193)	77 (76–77)	157 (156–158)	54 (52–57)	102 (97–108)
Greece	79 (78–81)	133 (131–135)	56 (55–57)	118 (116–120)	41 (39–44)	101 (97–106)
Iceland	94 (90–99)	172 (166–178)	68 (64–71)	111 (107–115)	44 (41–47)	65 (61–69)
Ireland	120 (117–123)	181 (178–185)	79 (77–81)	134 (131–136)	52 (49–55)	85 (81–89)
Israel	112 (110–115)	161 (158–165)	73 (72–75)	116 (114–118)	46 (43–48)	83 (79–88)
Italy	95 (94–96)	176 (175–178)	61 (60–62)	131 (130–132)	41 (39–44)	79 (75–83)
Luxembourg	115 (111–119)	227 (221–232)	80 (77–82)	162 (157–166)	51 (48–54)	102 (97–108)
Malta	110 (105–114)	184 (177–190)	64 (61–66)	108 (104–112)	45 (42–48)	73 (69–77)
Netherlands	86 (85–88)	157 (155–159)	68 (67–69)	116 (114–117)	55 (52–57)	73 (70–77)
Norway	77 (75–78)	156 (153–158)	66 (65–68)	128 (126–130)	50 (48–53)	77 (73–81)
Portugal	109 (107–111)	208 (206–211)	79 (78–81)	176 (174–178)	49 (46–52)	121 (115–127)
Spain	94 (93–95)	166 (164–167)	60 (59–61)	147 (145–148)	43 (40–45)	102 (96–107)
Sweden	84 (83–86)	143 (141–145)	65 (64–66)	115 (113–116)	44 (42–46)	71 (68–74)
Switzerland	88 (86–89)	165 (163–168)	63 (62–64)	128 (126–130)	43 (41–46)	74 (70–78)
UK	107 (106–108)	180 (179–181)	78 (77–79)	129 (128–130)	58 (54–61)	93 (88–98)
Latin America, Andean						
Bolivia	291 (273–311)	357 (325–392)	178 (169–188)	283 (270–296)	136 (115–160)	226 (187–272)
Ecuador	181 (177–185)	216 (212–221)	115 (112–118)	181 (177–186)	79 (71–87)	146 (133–159)
Peru	202 (194–210)	291 (281–303)	110 (105–114)	175 (169–181)	80 (69–92)	127 (110–147)
Latin America, central						
Colombia	167 (164–171)	216 (212–220)	115 (111–118)	235 (229–241)	67 (59–75)	155 (142–169)
Costa Rica	126 (123–129)	158 (154–162)	79 (77–81)	131 (128–134)	58 (53–63)	110 (103–117)
El Salvador	187 (183–191)	253 (248–258)	112 (109–115)	254 (248–260)	92 (84–101)	246 (230–263)
Guatemala	308 (300–317)	372 (364–380)	177 (172–182)	269 (263–276)	136 (122–152)	269 (247–294)
Honduras	221 (213–230)	262 (254–272)	163 (153–173)	208 (197–219)	182 (153–216)	164 (146–183)
Mexico	190 (187–193)	272 (268–277)	117 (115–119)	210 (206–213)	88 (84–93)	158 (149–168)
Nicaragua	216 (203–231)	280 (266–296)	116 (110–122)	178 (169–186)	99 (87–113)	174 (161–188)
Panama	157 (152–162)	175 (171–180)	82 (79–85)	135 (132–139)	68 (61–76)	126 (117–135)
Venezuela	158 (155–161)	222 (219–225)	106 (104–107)	179 (177–181)	81 (71–91)	177 (162–194)
Latin America, southern						
Argentina	140 (139–142)	256 (254–258)	102 (101–103)	198 (197–200)	83 (80–87)	156 (148–164)
Chile	181 (179–184)	292 (289–296)	96 (95–97)	192 (190–194)	60 (57–62)	115 (110–121)
Uruguay	125 (123–128)	228 (224–232)	96 (94–98)	193 (190–197)	82 (78–87)	161 (150–172)
Latin America, tropical						
Brazil	177 (164–192)	271 (259–283)	122 (121–124)	244 (241–247)	89 (83–96)	193 (185–201)
Paraguay	130 (126–134)	151 (147–155)	103 (100–106)	134 (131–138)	117 (98–139)	173 (158–190)
North Africa and Middle East						
Algeria	253 (222–288)	306 (270–346)	113 (100–127)	143 (128–159)	84 (67–106)	130 (102–165)
Bahrain	178 (147–216)	239 (207–276)	143 (134–153)	170 (162–179)	102 (88–118)	147 (130–167)
Egypt	154 (150–159)	293 (285–300)	156 (152–161)	229 (222–236)	121 (108–137)	201 (180–226)
Iran	168 (146–193)	231 (199–269)	109 (100–120)	185 (164–209)	95 (83–108)	183 (158–212)
						(Continues on next page)

Iceland were much larger than they were for Chile. The estimation of mortality shocks can also been seen in the case example of Iceland. In 1995, there were two avalanches that killed 34 people. Even 34 deaths is a fairly substantial number for Iceland and caused a sharp rise in 45q15 for that year. The Philippines is an example of a country with data from two independent sources—vital registration and sibling histories gathered in a household survey. In this case, the two sources were quite consistent and the Gaussian process regression estimates incorporated both sources with appropriate uncertainty intervals. Zambia had data from sibling histories only.

	1970		1990		2010	
	Women	Men	Women	Men	Women	Men
(Continued from previous page)						
Iraq	160 (146–175)	226 (207–246)	117 (103–133)	156 (139–174)	89 (76–104)	145 (122–172)
Jordan	145 (114–184)	197 (156–250)	120 (94–152)	122 (97–154)	97 (76–124)	94 (75–117)
Kuwait	119 (114–125)	180 (176–185)	134 (120–149)	178 (160–198)	128 (101–161)	186 (146–235)
Lebanon	98 (77–124)	185 (147–233)	75 (64–87)	169 (145–196)	52 (42–64)	125 (103–152)
Libya	163 (153–175)	189 (176–202)	113 (101–127)	150 (131–171)	90 (76–105)	115 (98–135)
Morocco	218 (178–267)	284 (232–349)	123 (116–130)	210 (198–223)	100 (83–119)	166 (137–200)
Occupied Palestinian territories	186 (172–202)	273 (248–300)	137 (125–149)	202 (183–222)	119 (105–135)	185 (163–211)
Oman	238 (188–300)	256 (202–324)	138 (113–169)	176 (145–213)	86 (76–96)	139 (124–155)
Qatar	110 (90–136)	185 (151–228)	85 (76–95)	96 (86–108)	67 (56–81)	81 (68–96)
Saudi Arabia	188 (149–237)	196 (156–246)	104 (83–129)	132 (106–164)	89 (75–106)	122 (103–144)
Syria	194 (179–209)	341 (312–373)	168 (150–188)	231 (202–265)	124 (108–141)	214 (186–246)
Tunisia	217 (211–225)	262 (255–269)	85 (81–89)	135 (130–140)	56 (45–70)	109 (91–130)
Turkey	137 (117–161)	261 (219–311)	115 (112–118)	220 (215–226)	85 (78–93)	174 (158–191)
United Arab Emirates	125 (113–137)	194 (178–212)	76 (68–84)	130 (119–142)	46 (40–53)	95 (85–108)
Yemen	285 (228–356)	349 (278–437)	212 (186–242)	273 (240–311)	165 (132–206)	234 (190–289)
North America, high income						
Canada	101 (100–102)	185 (184–187)	70 (69–71)	127 (126–128)	52 (50–54)	84 (81–87)
USA	126 (125–126)	228 (227–228)	89 (89–90)	167 (166–167)	77 (75–80)	130 (126–134)
Oceania						
Federated states of Micronesia	263 (241–288)	351 (317–389)	220 (200–241)	324 (293–357)	171 (149–197)	276 (240–318)
Fiji	210 (201–219)	315 (303–327)	219 (193–249)	330 (299–364)	234 (186–295)	316 (262–382)
Kiribati	238 (183–311)	299 (237–377)	200 (177–226)	307 (272–347)	167 (138–203)	309 (254–375)
Marshall Islands	207 (161–267)	291 (227–372)	214 (193–236)	304 (276–335)	219 (172–279)	283 (228–350)
Papua New Guinea	281 (259–306)	367 (343–394)	264 (243–288)	359 (332–389)	283 (249–320)	380 (343–422)
Samoa	223 (205–244)	362 (338–388)	150 (115–198)	273 (218–342)	94 (73–122)	150 (121–185)
Solomon Islands	249 (229–271)	343 (319–369)	201 (184–221)	313 (291–336)	187 (163–215)	293 (264–326)
Tonga	197 (161–241)	225 (193–264)	154 (119–199)	213 (168–269)	128 (101–162)	206 (169–252)
Vanuatu	265 (239–292)	355 (330–382)	214 (192–238)	320 (296–346)	165 (143–192)	271 (241–304)
Sub-Saharan Africa, central						
Angola	336 (317–356)	436 (413–461)	320 (301–339)	388 (367–411)	310 (288–334)	386 (358–416)
Central African Republic	329 (299–361)	452 (411–497)	478 (461–496)	600 (582–618)	491 (446–539)	600 (544–663)
Congo	337 (303–376)	383 (342–429)	370 (348–393)	421 (396–447)	349 (319–381)	415 (380–453)
Democratic Republic of the Congo	339 (305–378)	407 (363–457)	352 (327–379)	431 (405–459)	327 (300–356)	420 (387–455)
Equatorial Guinea	315 (293–338)	424 (401–448)	306 (285–328)	384 (362–406)	341 (314–371)	413 (384–444)
Gabon	232 (208–258)	310 (279–344)	225 (212–238)	319 (300–339)	313 (285–344)	412 (374–454)
Sub-Saharan Africa, east						
Burundi	434 (372–506)	493 (426–571)	420 (335–526)	498 (404–614)	426 (339–536)	516 (409–649)
Comoros	332 (276–400)	359 (301–430)	280 (221–355)	330 (266–409)	238 (188–301)	300 (244–368)
Djibouti	253 (232–276)	319 (296–342)	221 (203–241)	318 (295–342)	253 (226–283)	379 (342–420)
Eritrea	429 (355–519)	633 (525–763)	379 (356–404)	541 (514–570)	361 (298–438)	454 (372–555)
Ethiopia	430 (355–521)	583 (475–716)	440 (423–457)	617 (598–637)	372 (328–422)	484 (424–551)
						(Continues on next page)

The Gaussian process regression estimates tracked the data fairly closely, with the estimates after the most recent data point and before the oldest data point largely informed by the modelling process. As expected, uncertainty intervals widened as time from available data increased. Figure 1 shows data for Colombian men and shows how two datapoints have been coded as outliers in the time series.

Risk of mortality is generally higher (up to 2·2 times as high) for men than for women; however, in 2·5% of country-years, risk is higher for women than for men. By combining results for every country and weighting by population, we can examine the worldwide trend in $45q15$ for men and women from 1970 to 2010 (figure 2). Over this period, $45q15$ dropped by 19% for men and by 34% for women. Yearly rates of decline from 1970 to 1990

	1970		1990		2010	
	Women	Men	Women	Men	Women	Men
(Continued from previous page)						
Kenya	216 (175–266)	284 (236–343)	223 (213–235)	288 (275–302)	250 (212–296)	335 (285–393)
Madagascar	441 (401–486)	404 (369–442)	292 (279–307)	373 (356–391)	222 (190–259)	316 (276–362)
Malawi	308 (257–369)	298 (253–352)	332 (316–350)	428 (405–452)	517 (437–611)	696 (586–827)
Mozambique	292 (236–360)	329 (272–399)	229 (213–245)	342 (323–363)	470 (398–556)	630 (540–734)
Rwanda	338 (270–422)	426 (347–522)	443 (419–468)	560 (536–585)	296 (250–349)	410 (344–490)
Somalia	317 (292–344)	371 (345–398)	271 (249–296)	374 (349–401)	242 (214–273)	339 (306–377)
Sudan	218 (202–235)	331 (305–359)	203 (193–213)	253 (242–266)	207 (171–252)	273 (227–327)
Tanzania	234 (192–285)	304 (253–366)	284 (270–300)	365 (348–383)	318 (274–370)	459 (397–531)
Uganda	195 (161–237)	264 (220–317)	387 (367–407)	512 (493–533)	338 (296–387)	509 (455–571)
Zambia	363 (289–456)	430 (352–525)	471 (453–491)	555 (536–575)	606 (518–708)	733 (647–831)
Sub-Saharan Africa, southern						
Botswana	183 (143–235)	205 (165–254)	145 (117–179)	172 (141–209)	412 (346–490)	637 (544–746)
Lesotho	247 (195–312)	482 (398–584)	191 (172–211)	435 (410–461)	524 (451–609)	727 (643–823)
Namibia	234 (179–305)	468 (380–575)	212 (199–227)	437 (417–458)	444 (373–527)	682 (586–792)
South Africa	228 (187–278)	417 (334–519)	160 (151–169)	384 (364–404)	439 (399–484)	532 (466–608)
Swaziland	341 (261–446)	443 (364–539)	269 (238–306)	372 (339–407)	597 (517–689)	765 (692–845)
Zimbabwe	211 (163–272)	342 (276–423)	244 (230–259)	344 (329–359)	577 (471–708)	725 (613–858)
Sub-Saharan Africa, west						
Benin	260 (224–302)	364 (319–416)	180 (167–193)	316 (298–334)	224 (199–252)	363 (331–399)
Burkina Faso	276 (245–311)	376 (332–425)	266 (253–280)	400 (383–418)	259 (233–288)	398 (354–448)
Cameroon	270 (237–307)	372 (325–426)	242 (231–253)	355 (339–372)	347 (317–380)	439 (395–487)
Cape Verde	164 (143–189)	237 (207–272)	114 (106–123)	241 (226–257)	93 (79–108)	209 (182–240)
Chad	250 (218–287)	320 (280–365)	266 (253–280)	313 (298–328)	364 (326–407)	419 (378–464)
Côte d'Ivoire	279 (247–314)	337 (293–387)	280 (268–293)	434 (413–456)	385 (346–428)	472 (416–536)
Ghana	286 (246–332)	278 (239–323)	266 (251–282)	254 (240–268)	249 (232–268)	347 (325–371)
Guinea	291 (253–335)	331 (287–380)	268 (253–283)	323 (305–341)	325 (290–363)	431 (388–478)
Guinea-Bissau	285 (266–305)	377 (352–404)	270 (252–289)	347 (324–373)	307 (281–336)	397 (363–434)
Liberia	329 (287–377)	484 (428–547)	237 (213–263)	335 (308–363)	286 (256–320)	362 (328–398)
Mali	330 (292–372)	358 (321–400)	267 (254–280)	338 (326–351)	256 (231–282)	374 (345–406)
Mauritania	343 (299–395)	336 (295–383)	288 (271–307)	298 (281–317)	257 (227–292)	300 (265–339)
Niger	362 (320–409)	451 (391–520)	308 (294–323)	356 (337–376)	251 (229–275)	282 (252–314)
Nigeria	216 (186–251)	282 (244–325)	205 (186–227)	275 (253–298)	298 (271–327)	381 (356–408)
Sao Tome and Principe	202 (188–218)	286 (267–306)	160 (144–177)	213 (192–237)	147 (126–172)	201 (174–232)
Senegal	258 (227–292)	353 (310–402)	208 (198–219)	309 (294–324)	201 (182–222)	279 (252–308)
Sierra Leone	333 (288–385)	511 (442–589)	297 (269–327)	490 (445–540)	333 (303–367)	456 (415–500)
The Gambia	281 (258–305)	360 (337–384)	231 (212–252)	317 (295–341)	221 (200–245)	312 (283–344)
Togo	250 (219–285)	332 (291–379)	221 (209–233)	302 (288–317)	274 (242–309)	398 (349–453)

Country estimates are grouped into 21 regions on the basis of epidemiological profiles and geography. See text for definition of 45q15.

Table 2: 45q15 (uncertainty interval) per 1000 for women and men in 1970, 1990, and 2010

were 0·7% for men and 1·4% for women. From 1990, worldwide male 45q15 increased until 1995 and then began to decline. From 1990, female 45q15 declined at a much faster rate than did male 45q15, apart from during the period between 1994 and 2003, when both were declining roughly at the same pace. Worldwide, the gap between adult male and female 45q15 was 63 per 1000 in 1970 and increased to 80 per 1000 in 2010. In relative terms, the gap between sexes has widened even more, and accords with the sex difference in adult mortality in the USA and other high-income countries during the mid-20th century. Worldwide, the 1990s reversal in the trend in adult mortality is probably a result of the HIV pandemic and the sharp rise in adult mortality in countries of the former Soviet Union.

Figure 3 presents male and female 45q15 for 21 regions of the world, showing a high degree of variation between regions. For men, regional 45q15 varied from 182 to 413 per 1000 in 1970 and from 77 to 579 per 1000 in 2010— a 117% increase in the spread across regions. Rising inequality in adult mortality across regions is also evident for women, for whom 45q15 ranged from 101 to 347 per
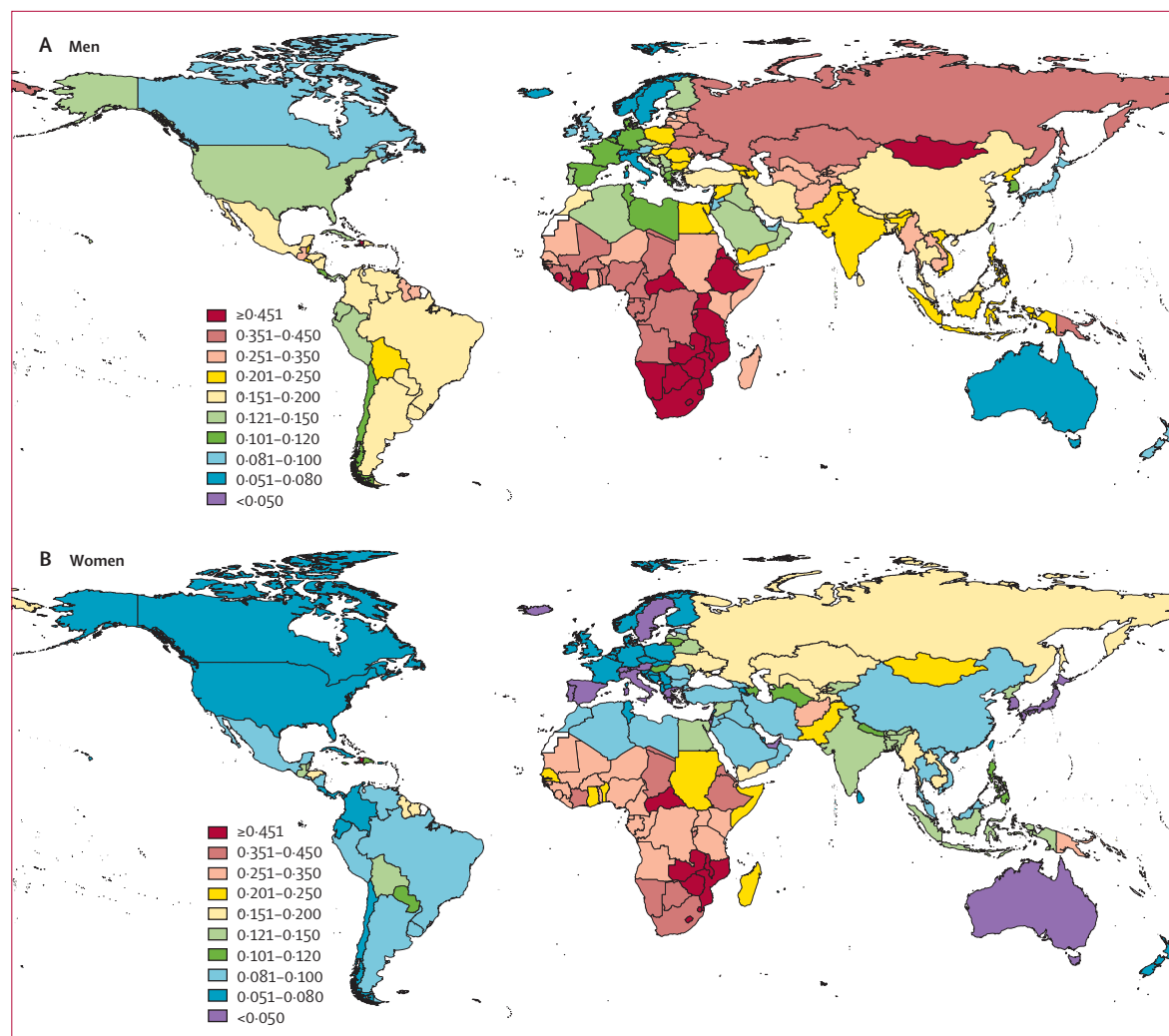
Figure 4: Worldwide adult mortality in 2010
Map shows 45q15, or the probability of dying before age 60 years conditional on survival to age 15 years.

1000 in 1970 and from 41 to 467 per 1000 in 2010. For men in 2010, there is a break at around 300 per 1000, with seven regions (all in sub-Saharan Africa, Oceania, eastern Europe, and central Asia) having risks of mortality that are notably higher than those in other regions. For women, the break is at around 200 per 1000 and only sub-Saharan Africa and Oceania are in the highest risk category. The global plateau in adult mortality beginning in the 1990s can be accounted for by these regions with huge increases in adult mortality. To put the risks of mortality now seen in southern Africa in 2010 in context (men 578 per 1000, women 446 per 1000), the 45q15 in Sweden in 1751 was 493 per 1000 for men and 437 per 1000 for women.[37]

Figure 3 also shows variation over time within regions. One of the most striking patterns is the rapid decline in adult female mortality in south Asia; in 1970 this was the region with the highest risk of female mortality and by 2010, 45q15 had fallen by 56%. Male 45q15 declined more

rapidly in Australasia than in other regions, whereas the rate of decline in North America was slower than it was in other regions. In southeast Asia, rates of decline have stabilised since the mid-1990s for men and women.

In all regions of sub-Saharan Africa, adult male and female mortality has begun to decline since 2005, partly as a result of reductions in HIV seroprevalence and perhaps also because of increased access to antiretroviral treatment. This decline is not a consequence of including HIV seroprevalence in the estimation model, since sibling history data also show a plateau or decline in mortality in recent years in Benin, Congo, Democratic Republic of the Congo, Nigeria, Rwanda, Tanzania, Uganda, and Zambia. The measured reductions range from 0% to 39%. Additionally, national vital registration data for South Africa show that adult mortality peaked in 2005 and has started to decline.

Table 2 shows our estimates and uncertainty intervals for 45q15 for men and women in all 187 countries every

20 years from 1970 to 2010. These results and the yearly estimates (available from the Institute for Health Metrics and Evaluation website) show substantial variation in levels and trends in 45q15 within regions.

Figure 4 shows worldwide adult mortality in 2010 (worldwide adult mortality in 1970 and 1990 is shown in webappendix pp 394–97). Substantial reductions in risks of adult male and female mortality have occurred over the 40-year period; however, increases have occurred in eastern and southern Africa and in eastern Europe. Some countries have unusual risks or trends in adult mortality. By 2010, Guatemala, Honduras, Haiti, Guyana, and Suriname had higher risks of adult mortality than did neighbouring countries. Within the European Union, there is substantial heterogeneity in risks of adult male and female mortality, most of which does not seem to be strongly related to income per head or development. In 2010, adult mortality is generally low in north Africa and the Middle East, apart from in Yemen (female mortality) and Morocco, Egypt, Yemen, and Syria (male mortality). In sub-Saharan Africa, several west African countries such as Benin, The Gambia, and Senegal have lower risks of mortality than do neighbouring countries, especially in women. Within south Asia, Afghanistan and Pakistan have higher risks of mortality than do India, Nepal, or Bangladesh. In southeast Asia and Oceania, Burma, Laos, Cambodia, and Papua New Guinea have high risks of adult mortality.

The ten countries with the lowest risks of adult male and female mortality in 1970 and 2010 are shown in figure 5. For male mortality, only three countries remained in this list over the 40-year period: Sweden, Norway, and the Netherlands. Notably, Australia moved from 44th in the 1970 list to sixth in 2010. Paraguay had a low risk of male mortality in 1970 but dropped to 70th in the list by 2010. The countries with the lowest risks of male mortality in 2010 represent several regions: northern Europe and Scandinavia, the Mediterranean, the Middle East, and Australasia. There has been more consistency in countries with lowest risk of female mortality: Greece, Sweden, Switzerland, Spain, Iceland, Italy, and Cyprus all remained in the top ten between 1970 and 2010. In 1970, the countries with the lowest risks of female mortality were all in Europe or the Mediterranean. By 2010, South Korea, Japan, and Australia had joined the list. South Korean women have lower risk of mortality than do Japanese women (notably, Japanese men do not make the top ten list in either decade—they ranked 16th in 1970 and are 12th in 2010). Also for women, northern European countries tended to fall in the ranking, whereas southern European and Mediterranean countries improved.

The development of annual estimates of adult mortality enables us to examine more carefully the rates of change. The focus on rates of change provides some insight into national performance in reducing adult mortality. Table 3 shows the distributions of yearly rates of change in adult mortality by decade. For both men and women, in all four decades both the mean and median rates of change were negative. Mean and median rates of change in all time periods were more negative for women than for men, suggesting faster declines for women. Table 3 also provides a measure of inequality in the rates of change: the SDs across countries were similar in the 1970s, 1980s, and 2000s for both men and women. However, in the 1990s, there was a much greater dispersion of rates of change; in other words, many countries actually had rising adult mortality. This period of increased heterogeneity in the trend in adult mortality seemed to have disappeared by the 2000s. Table 3 also shows the same analyses with exclusion of sub-Saharan Africa, eastern Europe, central Europe, and central Asia. For the remaining regions of the world, mean, median, and distribution of rates of change have been consistent over four decades.

Figure 6 shows the yearly percentage decline in 45q15 from 1970 to 2010 by country. The areas with stable or increasing risk of adult mortality are evident and reflect the rise in prevalence of HIV in sub-Saharan Africa, the increase in adult mortality in eastern Europe and countries of the former Soviet Union, and the plateau in decline for southeast Asia, dominated by the Philippines, Indonesia, and Thailand. Additionally, some countries such as Paraguay had unusually low risks of adult mortality in 1970 and have shown increases in risk over the past 40 years. Among high-income countries, the USA is notable for having a rate of decline of less than 1% per year, as are Norway (female mortality only) and Spain (male mortality only).

Discussion

Our analysis of all available empirical data for adult mortality from 1970 to 2010 for 187 countries shows that the rates of change for adult mortality are substantially more varied than are those for mortality in children under 5 years of age (Rajaratnam J K, et al, unpublished data). Risk of mortality is generally higher for men than for women; however in 2·5% of country-years, risk is higher for women than for men. There is also a widening gap between risks of male and female mortality.

Despite the sex differences in mortality, there is substantial consistency in time trends; the correlation in yearly rates of change for male and female adult mortality is 0·70. By comparison, the correlations between rates of change in adult mortality and rates of change in under-5 mortality are 0·24 and 0·35 for males and females, respectively. A plausible explanation for these findings is that determinants of mortality in adults are substantially different from those for mortality in children. The unique patterns and trends in adult mortality highlight the importance of tracking adult mortality as distinct from metrics that focus on separate or wider age ranges, including under-5 mortality and life expectancy at birth.

An important exception to the correlation of trends for male and female mortality is south Asia. In 1970, 45q15 was higher in women than in men in most countries in the region. However, risk of mortality has declined substantially faster in women than it has in men, such that in 2010, female mortality is substantially lower than male mortality. The problem of "missing females"[82–84] would seem to be improving in south Asia, at least with respect to sex differences in mortality.

We have shown that rates of decline in 45q15 vary substantially between countries within a decade and across decades even when mortality shocks due to wars, disasters, or famines are excluded from the analysis. Five factors might explain the changes in adult mortality: the diseases of affluence;[85] socioeconomic development;[86] improved health technologies;[87] social dysfunction in the aftermath of the collapse of the Soviet Union;[88] and the HIV epidemic.[76] Increases in prevalence of income-related risk factors for non-communicable diseases might account for increases in adult mortality in some countries with rapidly rising income, such as the Philippines and Indonesia. Adult mortality has not, however, increased in many other countries with similarly rising income. The predicted decline in adult mortality from rising levels of development as a result of improved calorie intake, control of infectious diseases, and access to health care is manifesting itself differently in each region. Socioeconomic development also has an important interaction with improvements in health technologies such as antihypertensive drugs, statins, or invasive therapies for coronary heart disease. The rise in mortality in many countries in or related to the former Soviet Union is well documented as are the unprecedented increases in adult mortality in eastern and southern Africa because of HIV. A substantial component of the variation in risk and rates of change, however, seems to be poorly explained by any combination of these theories. Examples include the slower rates of decline in mortality in the USA compared with many other high-income countries or the stable trends in Indonesia. We hope that the evidence presented in this report will stimulate a debate on alternative theories of the health transition that can account for the diversity of patterns reported.

Adult mortality has long been thought to change slowly whereas infant or under-5 mortality is seen as a more sensitive indicator of general population health status.[4] Indeed, yearly rates of decline for adult mortality at the global level have ranged from –0·7% to 2·1%; for children, yearly rates of decline are steeper and range from 1·0% to 3·0% (Rajaratnam J K, et al, unpublished data). The range of rates of change in adults is larger than the range for children and also, as noted, only weakly correlated with under-5 mortality. Well documented periods of rapid decline, such as in South Korea between 1990 and 2010, when adult mortality declined by over 50%, or between 1995 and 2010 in Estonia, when there was greater than 35% decline, show that rapid progress is possible. These bursts of accelerated decline in mortality suggest that policies adopted in one setting could be transferred to other settings. We believe that one important follow-up to this report will be to study these periods of rapid improvement in order to understand them better or at least to develop testable hypotheses. The assumption that policies that reduce under-5 mortality will automatically have benefits in reducing mortality in women and men is no longer defensible.

The empirical record presented in this study documents the effect of war on adult mortality. Some investigators have argued that war has a limited effect on mortality.[89] But in 18 countries, we recorded substantial increases in mortality documented in vital registration systems or in sibling history data from surveys. In these cases, the effect has been larger in absolute and relative terms on male mortality than it has on female mortality: mortality shocks for men are a mean 6·1 per 1000 points greater, and 7% greater, than mortality shocks for women. The relation between observed increases in the empirical adult mortality data and numbers of war-related and disaster-related deaths recorded in the Uppsala Conflict Data Program and Centre for Research on the Epidemiology of Disasters databases varied across countries. The correlation between observed increases in mortality and the war-related and disaster-related death rates in the same country-years is only 0·56. Despite our efforts to take into account war shocks in country-years without robust data, clearly this is an area that is subject to substantial uncertainty. Our findings, however, highlight the continued importance of measuring the effect of war and other shocks on adult mortality.
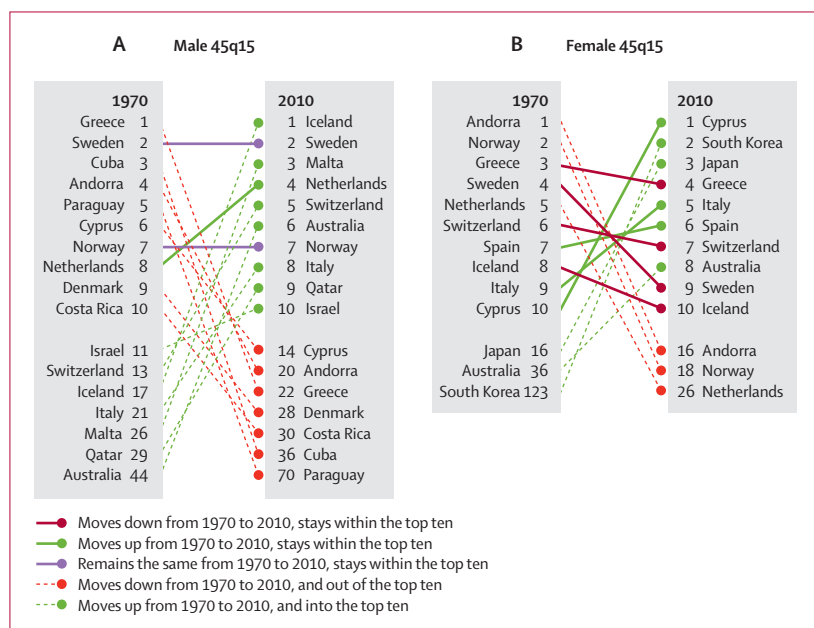

Figure 5: Countries with the lowest risks of adult mortality in 1970 and 2010 for men and women
Arrows indicate change in rank between 1970 and 2010.

Although we have been able to examine 3489 country-years of vital registration data, 257 survey-based observations, 25 censuses, 118 sample registration systems, demographic surveillance system results, and points from other sources, there are still substantial gaps in the data. Our estimates of adult mortality were based on the best available evidence; however, there are trends, especially over short periods, in datasets that need further investigation. For example, the sibling histories for Benin suggest female 45q15 reduced to as low as 163 per 1000 in the early 1990s. Since we did not find any objective reason in the data or the analysis to reject this datapoint, we

	Worldwide						Worldwide (excluding sub-Saharan Africa, eastern Europe, central Europe, and central Asia)					
	Men			Women			Men			Women		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
1971–80	–0·58%	–0·58%	0·0096	–1·41%	–1·40%	0·0103	–0·86%	–0·80%	0·0089	–1·75%	–1·68%	0·0100
1981–90	–0·66%	–0·65%	0·0114	–1·01%	–1·18%	0·0121	–1·05%	–1·07%	0·0103	–1·43%	–1·51%	0·0102
1991–2000	–0·17%	–0·45%	0·0168	–0·30%	–0·85%	0·0193	–0·79%	–0·86%	0·0118	–1·08%	–1·16%	0·0111
2001–10	–0·87%	–0·85%	0·0098	–1·22%	–1·25%	0·0096	–1·17%	–1·19%	0·0090	–1·46%	–1·46%	0·0086

Statistics are computed only for the middle 95% of the distributions to exclude mortality shocks.

Table 3: **Distributions of yearly rates of change in adult mortality (%), by decade**
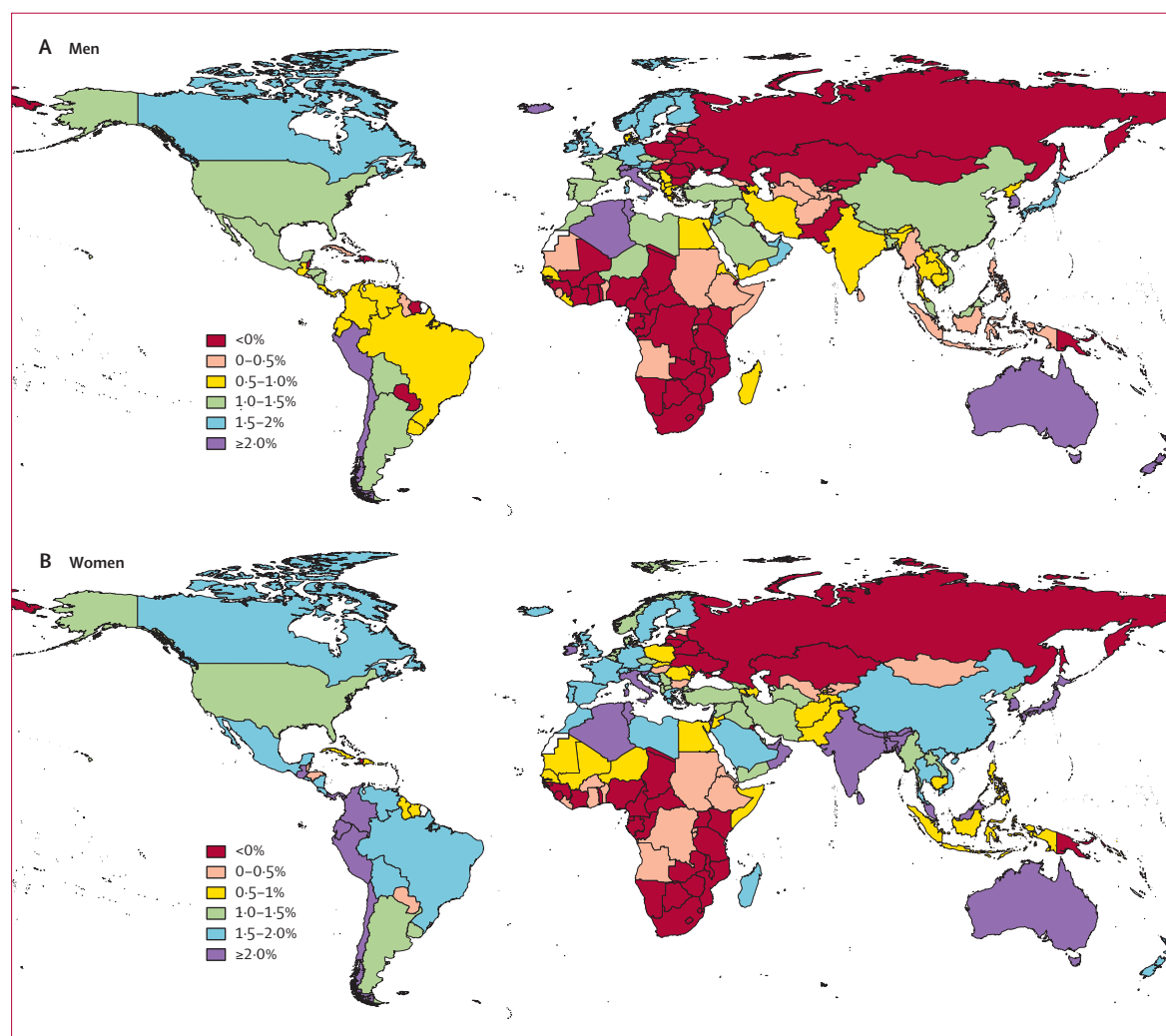
Figure 6: **Yearly percentage decline in adult mortality, 1970–2010**

included it in our estimates. Consideration of neighbouring countries and levels of socioeconomic development, however, are a cause for concern. In South Africa, the rise in adult female mortality in the 1990s was twice the rise in male mortality, largely because of the disagreement between levels provided in the sibling history estimates and those shown in vital registration data for men. Because the vital registration system in South Africa was undergoing substantial improvement in coverage during the mid 1990s, we chose to exclude the earlier data points from our analysis since it is difficult to tease out real trends in mortality from changes in the vital registration system.[90,91] The effect of this approach and differences between vital registration and sibling history data for men has resulted in the striking differences between male and female mortality. For some countries, especially those with large corrections to completeness of vital registration or sample registration systems or those with only a limited number of surveys, care should be taken to not over interpret short-term trends in the results. Because we have developed and applied a set of methods that are transparent, available in computer code, and replicable, we hope that researchers will be able to further refine and advance this analysis of adult mortality.

Our estimates of adult mortality are substantially different from those reported by UNPD. For overlapping years, the correlation is 0·84 for men and 0·87 for women. Regionally, our estimates for south Asia, southeast Asia, Latin America tropical and North Africa and the Middle East are substantially lower than are those reported by UNPD. These differences seem to be a result of variations in the data examined, our application of newer methods to different data sources, and the use of model life tables by the UN based on data mainly gathered before 1970. The effect of the UN's methods can even be seen in countries with complete vital registration systems such as the USA or UK, for which UNPD estimates differ from the data by 19·3% and 12·2%, respectively, in 2007.[7] Furthermore, for some regions, the UN has taken UNAIDS estimates of HIV mortality and added these to the results of their demographic estimation.[92] In this study, we used data sources for mortality from all causes, and did not use disease-specific transmission models or assumed case-fatality rates. Although WHO has not produced a coherent time series of 45q15, it has generated cross-sectional estimates. Because of changing datasets and the application of alternative methods from year to year, their 45q15 estimates have varied substantially over years for the same country. For example, in Côte d'Ivoire, WHO estimates of female 45q15 range from 355 to 502 during the years 2000–07. Hopefully, our carefully constructed database and application of improved methods will be informative to both the UNPD and WHO in their future efforts at mortality estimation. Use of the best possible estimates of adult mortality is important for planning purposes and as a direct input into the estimation of maternal mortality.

In some countries with large HIV epidemics such as Swaziland, risk of adult mortality reach very high levels. The increase in 45q15 seems to be larger than population HIV seroprevalence. These findings can be understood in terms of several potential factors. First, adult mortality in southern Africa—especially in men—was high before the start of the HIV epidemic (in some cases risk of death was around 400 per 1000). Second, because of the concentration of HIV in adults aged 15–59 years, the average seroprevalence in that population will be higher than the seroprevalence in the entire adult population. Third, because the natural epidemic curve for HIV can lead to high prevalence and then drop to an equilibrium prevalence, rises in period estimates of 45q15 can be larger than the rise in the cohort 45q15. Finally, there might also be secondary effects of large HIV epidemics on other causes of death mediated through economic, social, and domestic disruption.

Our improved methods predicted estimates of mortality for countries with no data with 14% error and generated forecasts with 6·3% error (by use of out-of-sample and out-of-time predictive validity tests). Nevertheless, the strongest step a country can take to improving the surveillance of adult female and male mortality is to strengthen national vital registration systems. No amount of post-data collection analysis will be as effective as implementation of a complete system.[22,23,32] For countries without complete vital registration systems, we found that survey data for sibling histories were very informative, with a few notable exceptions. We believe more widespread and frequent use of sibling histories in surveys would strengthen surveillance of adult mortality. In countries with HIV epidemics where antiretroviral use is being scaled up, survey data for sibling histories can prove very useful for documenting effects on mortality.

Every year, more than 7·7 million children die before their fifth birthday; however, over three times that number of adults—nearly 24 million—die under the age of 60 years. The prevention of premature adult death is just as important for global health policy as the improvement of child survival. The global health community needs to broaden its focus and to learn from measures applied in countries such as Australia and South Korea to ensure that those who survive to adulthood will also survive until old age. This refocus will require much greater efforts to equip all countries with reliable and timely mortality surveillance systems, preferably complete vital registration systems, to guide prevention policies and programmes.

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