Model-based estimates of adult mortality in sub-Saharan Africa: comparisons with data on parental and sibling survival

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Abstract

Due to the lack of civil registration data in sub-Saharan Africa, adult mortality is often estimated in two stages; first, measures of child survival are combined with model schedules of mortality, then AIDS-related deaths are factored in. Model-based estimates are mostly sensitive to the choice of age pattern used to infer the background mortality and to violations of assumptions made to predict the number of AIDS-related deaths. They need to be regularly evaluated against survey or census data. In this paper, United Nations estimates of adult mortality are compared with survival probabilities calculated from sibling histories collected in DHS surveys. UNAIDS orphan prevalences are compared with proportions of orphaned children observed in censuses and household surveys. If parental and sibling survival provide plausible lower bounds, then adult mortality is underestimated in countries severely affected by the HIV/AIDS epidemic, especially in Southern Africa and among males. In addition, as the HIV epidemic unfolds, the age patterns of mortality derived from DHS surveys differ markedly from model outputs.

1 INTRODUCTION

The key developments in measuring adult mortality in countries with deficient vital statistics date back to the late 1970's and early 1980's. At that time, demographers devoted much of their research efforts to unconventional approaches to compensate for the lack of registration-type data (Hill et al. 2005). Improvements were made to intercensal techniques (Preston 1983, Preston and Bennett 1983), and death distribution methods were developed to evaluate the completeness of death reporting in censuses or civil registration (Hill 1987, Bennett and Horiuchi 1984). Data on the survival of parents started to be collected to provide indexes of adult mortality through the orphanhood technique (Brass and Hill 1973, Blacker 1977). Later on, in an attempt to better estimate maternal mortality with the sisterhood method, an equivalent of birth histories for the survival of siblings was included into the questionnaires of Demographic and Health Surveys (DHS) and other survey programs (MICS, WHS).

In sub-Saharan Africa, with the notable exception of Zimbabwe and South Africa (Dorrington et al. 2001, Feeney 2001), gains in the completeness of civil registration since the 1980's have lagged far behind these methodological developments. Consequently, our knowledge of adult mortality is mostly based on patchy and often discrepant estimates obtained from unconventional approaches. Because they are derived from levels of all-cause mortality, accurate estimates of maternal deaths and the prevalence of orphanhood also remain elusive. In some countries (Angola, Guinea Bissau, Gabon or Somalia), data on adult survival are virtually nonexistent, and age-specific death rates are simply estimated by combining model schedules of mortality with an index of child survival. In other countries, indirect methods are used, but they yield only probabilities of survival for specific segments of the adult ages ($_{10}p_{25}$, $_{10}p_{35}$, etc.). When it is possible to estimate mortality over a wider range of ages (as is the case with DHS sibling histories or recent household deaths), mortality rates obtained for the elderly are often unreliable because of age exaggerations and age heaping. Even for prime-age adults, measures of mortality can be heavily distorted by recall errors and selection biases. Another serious limitation of unconventional estimates is that they do not provide the time series needed to fully reconstruct past trends in mortality. They refer only to a few points in time, often outdated and sometimes ill-defined, especially when mortality trends have been disrupted by wars or the HIV epidemic.

For all these reasons, model life tables remain an indispensable part of the estimation methodology of African adult mortality. For instance, for around four out of five countries of the region, a two-step procedure is used by the Population Division of the United Nations (UNPD). First, a level of background mortality is obtained by combining a summary measure of child mortality (such as the probabilities $_5q_0$ or $_1q_0$) with a model schedule of mortality. Since 2004, the UNPD has used the two-parameter Brass logit model for a handful of countries of Western Africa, in order to give more importance to direct and indirect estimates of adult survival (United Nations 2009b). In this case, the age pattern of mortality is not solely defined by the choice of the life table; it can change according to the observed relationship between adult and child survival. In a second step, the UNPD factors in the demographic impact of the HIV epidemic. This is done by calculating the number of

AIDS-related deaths from trends in HIV prevalence provided by the Joint United Nations Programme on HIV/AIDS (UNAIDS). This calculation relies on numerous assumptions about age and sex distribution of infections, survival from infection to death, mother-to-child transmission, reduced fertility of infected mothers and impact of ART (United Nations 2005b). The World Health Organization (WHO) adopts a similar approach to produce its own estimates, with a modified version of the Brass logit model (Murray et al. 2003)[1].

The use of a child-mortality matching approach by UN agencies is motivated by difficulties of reconciling discrepant estimates obtained from different sources and methods, and by a general consensus that genuine measures underestimate mortality (Reniers et al. 2011). However, it is problematic to infer adult mortality from child survival, especially in countries with high HIV prevalence, and this paper calls for a more extensive use of available estimates of adult mortality.

First, model-based estimates are very sensitive to the selection of an age pattern of mortality. For example, in the North model of Coale-Demeny life tables, the probability of a female surviving to age 5 ($_5p_0$) implied by a life expectancy at birth of 50 years corresponds to a probability of dying between ages 15 and 60 ($_{45}q_{15}$) of 0.337. With the South Model, the same proportion of females surviving to age 5 corresponds to a life expectancy of 54 years and a probability $_{45}q_{15}$ that is 30% lower (0.243).

Secondly, model life tables currently in use are primarily drawn from the historical experience of Western countries, and their adequacy for countries with incomplete data may be questioned. Sankoh et al. (2006) showed that age patterns of mortality observed in demographic surveillance sites in sub-Saharan Africa do not all conform to Coale-Demeny life tables.

Thirdly, in countries severely affected by HIV/AIDS, the use of model life tables is restricted to the estimation of *background* mortality, to which AIDS-related deaths are added. However, in some of the hardest-hit countries, it is no longer tenable to make no-AIDS scenarios (Heuveline 2003). A case in point is the problem of indexing a model schedule with available estimates of child survival. It is unclear how risks of dying in childhood net of AIDS can be inferred from DHS birth histories. In addition, the trends observed over time in child mortality may not reflect the trends in mortality of the uninfected adult population.

Because of these limitations, model-based mortality rates need to be regularly evaluated against survey or census data. For each revision of the *World Population Prospects*, the UNPD undertakes a very comprehensive review of empirical estimates. When important discrepancies are apparent with model outputs, the background mortality is revised and the procedure is repeated until a *reasonable agreement* is achieved (United Nations 2005b). However, this external validation contains a considerable element of judgment. Prior to the publication of the *World Mortality Reports*, the methodology was neither explicit nor replicable, because the UNPD did not publish comparisons between model-based and empirical

[1]For all but a few countries of the region, the WHO does not use a parameter describing the level of adult mortality, and its approach thus reduces to a uni-parametric model age pattern (I refer here to uni-parametric models when a single entry index is used, although it could be argued that the choice of the "family" is in itself a second parameter).

death rates. The 2007 *World Mortality Report* compiled and summarized various sources of estimates but levels of mortality obtained from data on the survival of close relatives were not included in this report[2].

This paper intends to fill this gap by presenting systematic comparisons between model-based and kin-based estimates of adult mortality. Previous comparisons of this kind have been of two types. Firstly, mortality rates derived from DHS sibling histories have been broadly evaluated against United Nations estimates (Stanton et al. 2000, Gakidou et al. 2004, Reniers et al. 2011). Secondly, proportions of orphaned children reported in household surveys and censuses have been compared with orphanhood prevalence estimated by Spectrum, the software used by UNAIDS to predict the demographic impact of the epidemic (Grassly et al. 2004, Robertson et al. 2008). This software relies on assumptions similar to those made by the UNPD to estimate the number of AIDS-related deaths. In its latest version, the cohort component projection model built within Spectrum starts with the no-AIDS life expectancies of the 2010 Revision of the WPP. Therefore, comparing Spectrum-based and observed proportions of orphaned children is a form of external validation of UN estimates[3].

Updating previous comparisons is timely, because mortality estimates are constantly being improved from one revision of the WPP to another. For instance, the AIDS-component of mortality has been reduced as a result of a downward adjustment of HIV prevalence by UNAIDS to match more closely the results of HIV testings included in DHS surveys (Gouws et al. 2008). In a majority of countries, the age pattern used to infer background mortality has also been modified during the last decade. For instance, in the early 2000s, Bradshaw and Timaeus (2006) concluded from evidence from orphanhood data, DHS sibling histories, as well as other surveys and censuses that "in recent years the Population Division's extrapolations using Princeton North model life tables have overestimated non-AIDS adult mortality in large parts of the region". In response to this criticism, the UNPD adopted the South model for many countries in 2004, but most of them have been switched back to the North model in the last revision. Such shifts result in significant changes in mortality. For the period 2000-2005, the probability of dying between ages 15 and 60 ($_{45}q_{15}$) more than doubled in Togo and Côte d'Ivoire between the revisions 2008 and 2010.

This study has three objectives: (1) to re-examine if the South model is preferable to the North model, (2) to assess if the agreement between model-based and kin-based estimates varies with the HIV prevalence, (3) to analyze discrepancies between both types of estimates at the country level. The working hypothesis is that kin-based estimates provide at best lower bounds, because of underreporting of sibling deaths and misreporting of orphanhood status. If this hypothesis holds true, then mortality has been underestimated in

[2]Unless they had been incorporated into official national life tables.

[3]Alternatively, one could compute probabilities of dying from data on parental survival through the orphanhood technique (Timaeus 1992) and evaluate them against UNPD life table indexes. However, the HIV epidemic has rendered the orphanhood technique obsolete in its original form. Adjustments developed by Timaeus and Nunn (1997) are considered provisional and they are limited to female mortality.

a few countries where the South model has been used until the revision 2010. In addition, in Southern Africa, where the West model is used in several countries to infer background mortality, adult mortality seems underestimated, especially among males, probably because the life expectancy assumed for the uninfected population is too high. Age patterns of mortality increases due to AIDS derived from DHS data also differ markedly from model outputs.

This paper is organized as follows. Section 2 summarizes methods used by UN agencies to model death and orphan rates (2.1), and then describes methods used here to derive estimates from parental and sibling survival data (2.2). Section 3 proceeds with comparisons between kin-based and model-based estimates. Descriptive statistics are presented (3.1), as well as results from linear-mixed effects models incorporating both fixed-effects parameters and a random intercept varying by country (3.2). Section 4 concludes with a discussion of the results and their implications.

2 DATA AND METHODS

2.1 UNITED NATIONS ESTIMATES OF MORTALITY AND ORPHAN RATES

2.1.1 A child mortality-matching approach to infer mortality at all ages

Since 2004, several UN agencies[4] collaborate within the Inter-agency Group for Child Mortality Estimation (IGME) to obtain consistent and accurate child mortality rates. For most countries in sub-Saharan Africa, they serve as the starting point of the calculation of a complete no-AIDS life table that pertains to the uninfected population. In the 2010 Revision of the WPP, they were combined with a uni-parametric model schedule in 38 countries out of 47[5]. The logit model, which has an additional parameter explicitly related to adult survival, was used in 7 countries, and only two countries did not require the use of any standard (Réunion and Maurice). *Ad hoc* adjustments were made to take into account additional deaths due to wars or famines (DR Congo, Liberia, Rwanda, Somalia, etc.).

The demographic impact of HIV/AIDS was modeled in 37 countries in which the HIV prevalence ever exceeded 2% among the population aged 15-49 between 1980 and 2009. The UNPD started with country-specific estimates of HIV prevalences provided by UNAIDS and obtained from the EPP model (Estimation and Projection Package). This model fits a smooth trend through past estimates from surveillance and survey data (Brown et al. 2006; 2008; 2010). From the reconstructed trends in prevalence, the UNPD derived yearly probabilities of infection by sex and age, using a method inspired by the work of Hallett

[4]UNICEF, WHO, The World Bank and UNPD.

[5]Countries that are not considered here are: all countries from Northern Africa (Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Sudan, Tunisia, Western Sahara), Seychelles and Saint Helena (because their population did not exceed 100 000 inhabitants in 2010, and no estimates of adult mortality are available from the UNPD) and Mayotte (because estimates of orphan prevalence cannot be computed from Spectrum). In Table 1, the number of countries for the 2000 Revision was 46, because this Revision did not produce life tables for São Tomé.

et al. (2008). This methods aims to decompose observed changes between successive cross-sectional measures of age and sex-specific HIV prevalence into two components: (1) the rates of new HIV infections and (2) the rates of AIDS deaths. By approximating the latter with standard patterns of survival after infection (Todd et al. 2007), it is possible to estimate HIV incidence. This approach is also taken in Spectrum to compute incidence rates and derive standard patterns of the distribution of new HIV infections by age from DHS (Stover et al. 2010)[6].

The UNPD assumed that the distribution of infections by age follows a Weibull distribution, and remains fixed over time. The standard used for Africa predicts a mean age at infection of 32 years for males and 27 years for females. The infected population was then projected over time between different stages of disease progression (infected, full-blown AIDS and under treatment) using a multi-state approach. The survival time was also modeled with a Weibull distribution. It is noteworthy that this pattern did not vary with the age at infection, but it differed by sex to reflect younger ages at infection among females. The number of children under five who contract the virus from their mother and will die of AIDS was then estimated from the number of HIV positive mothers, accounting for a reduced fertility of infected mothers, pediatric treatment, and interventions to prevent the vertical transmission (PMTCM).

This modelling of HIV/AIDS is the most important part of the mortality estimation for countries hardest hit by the epidemic. However, estimates are also sensitive to the choice of the age pattern used to infer background mortality. Table 1 presents the distribution of model age patterns used in successive revisions of the WPP. This table also shows how adult mortality rates have been revised downward since the 2000 Revision, using as a reference the regional averages of the life table probability ${}_{45}q_{15}$ for the period 2000-2005.

Table 1 about here

Overall, background mortality has been mostly obtained from model schedules developed by Coale et al. (1983) or the United Nations (1982)[7]. To get a sense of the variation between these patterns, Fig. 1 displays the relationship between the probabilities ${}_5q_0$ and ${}_{45}q_{15}$ embodied in the models. Mortality rates extracted from demographic surveillances sites (DSS) in sub-Saharan Africa are overplotted. Estimates from the Human Mortality Database (HMD) are plotted as well[8].

Figure 1 about here

[6]The UNPD does not use Spectrum for the HIV modelling but a program called abcDIM. There are slight differences between the two programs, with regard to the implied age patterns of infection, the trends in the sex ratio of incidence, and the disease progression (Mulder and Johnson 2005).

[7]For the WPP 2010, both UN and Coale-Demeny age patterns were revised with a modified Lee-Carter approach to be extended to very low levels of mortality (up to $e_0 = 100$), but this does not affect estimates for sub-Saharan Africa.

[8]This database covers selected life tables from 37 industrialized countries where death registration is virtually complete. Available at www.mortality.org (University of California, Berkeley, USA, and Max Planck Institute for Demographic Research, Germany.) See Reniers et al. (2011) for a similar plot with DHS sibling estimates.

For a given level of child mortality, model schedules exhibit very different chances of surviving in adulthood. It is well known that the South model is characterized by low risks of dying between ages 5 and 60, relative to child and infant mortality. This pattern conforms to some outliers from the HMD database, and also follows quite closely the trends observed in various demographic surveillance sites in Senegal (Bandafassi, Mlomp and Niakhar). However, the probabilities ${}_{45}q_{15}$ lie far below estimates from other demographic surveillance sites for a given value of the probability ${}_5q_0$. The patterns implied by the North and West models are more in line with the cloud formed by HMD estimates. For females, these two models have a roughly similar child mortality (for a same life expectancy at birth), but the West model encompasses a somewhat higher infant mortality. In adulthood, the West model corresponds to slightly higher mortality rates for females when the life expectancy is below 60. The ratio of North to West death rates increases steadily as the mortality decreases. The differences between the West and North models are more pronounced for males, as can be seen in Fig. 2 when life expectancy at birth reaches 65.

Figure 2 about here

Overall, these two patterns predict lower adult mortality rates than most of the estimates derived from demographic surveillance sites for a given level of child survival. Part of this difference can be ascribed to adult mortality increases due to AIDS, which undoubtedly distort age patterns in Tanzania, Mozambique or South Africa. But the probability ${}_{45}q_{15}$ calculated from the DSS maintained in Butajira (Ethiopia) is also higher than assumed by the North and West patterns, although AIDS was not an important cause of death in this site in the period 1995-99 (Adjuik et al. 2006). The very high risks of dying in adulthood in Bandim (Guinea-Bissau) are anomalous and most likely stem from data deficiencies (INDEPTH 2002). Finally, the Far Eastern pattern, known to reflect high rates of mortality from tuberculosis, exhibits extreme levels of adult mortality for a given level of child survival. This pattern is currently used by the United Nations to model background mortality in Eritrea and South Africa.

Because of the large variations between different model schedules, shifts from one schedule to another will translate into significant differences in the resulting estimates. As noted previously, these shifts have been quite common between successive revisions of the WPP: since 2000, the age pattern used by the UNPD changed at least once in 24 African countries out of 47, and it changed at least twice in 13 countries. Most of the shifts were made from or to the North model of Princeton life tables. This pattern has historically been preferred for tropical Africa because it has one feature - low infant mortality relative to mortality at 1 to 5 - that is customary in African populations (Brass et al. 1968, Ekanem and Som 1984). It also displays high death rates from tuberculosis, though less extreme than the Far Eastern model. This second trait makes it attractive for Africa, because the age pattern of mortality from tuberculosis is close to the age pattern of mortality from malaria, a major cause of death in the region (Preston 1976).

In the 2000 Revision, the North model covered all countries for which adult mortality was derived from child survival, except 5[9]. In 9 countries, the estimates were directly inferred from adjusted household deaths, intercensal survival ratios or orphanhood data[10].

Between the 2000 and 2002 revisions, the modeling of the no-AIDS mortality changed in 16 countries. In 9 of them, the North model was adopted instead of country-specific age patterns or estimates from neighboring countries[11]. In 4 countries, the West model was preferred to the North (Congo and Botswana), South (Lesotho) or Chilean models (Cape Verde). The Far Eastern model was favored in Eritrea (rather than the West), and adopted for South Africa, instead of a life table derived from orphanhood data collected in the 1995 October Household Survey.

Several authors stressed the need to adopt model schedules with lower adult mortality rates than the North model - especially in Central and Western Africa (Timaeus 1993; 1997; 1999). Grassly et al. (2004) recommended that the United Nations replace the North and West models by the South pattern, because orphan prevalences implied by these model schedules were too high. In response to these observations, the predominance of the North model was reduced between the 2002 and 2004 revisions: Malawi, São Tomé and 7 countries located in Western Africa were switched from North to South model, resulting in a decrease of about 25% in their probabilities ${}_{45}q_{15}$. The South model was also adopted for Mali and Tanzania (for which the 2002 estimates were derived from census data). At the same time, Swaziland and Namibia (as well as Djibouti) were switched from North to West model, which has since been retained for most countries of Southern Africa. Note that the effect of these shifts cannot be gauged from the probabilities ${}_{45}q_{15}$ presented in Table 1, because they were accompanied by a downward revision of HIV prevalence by UNAIDS.

On average, the probability ${}_{45}q_{15}$ for the period 2000-2005 was further revised downward by about 15% in the 2006 Revision. Again, this resulted mainly from lower estimates of HIV prevalence as assessed by UNAIDS, both because surveillance sites were progressively extended into remote rural areas (Brown et al. 2006), and because household-based HIV testings (such as those included in DHS) indicated lower prevalence than antenatal clinic data. But changes were also made for background mortality. In 6 Western African countries (Burkina Faso, Gambia, Mali, Mauritania, Niger and Senegal), the two-parameter Brass relational model was used in combination with a standard derived from demographic surveillance sites (INDEPTH 2004). The α and β parameters of this model were estimated from direct and indirect estimates of child mortality (${}_5q_0$), as well as adjusted estimates of adult mortality (${}_{45}q_{15}$). Depending upon the availability of data, recent household deaths, orphanhood, siblings histories and estimates from demographic surveillance sites were con-

[9] In Comoros, Eritrea and Liberia, the West model was preferred, in Cape Verde the Chilean model was used and the South model was retained for Lesotho.

[10] In 7 other countries, the methodology used by the UNPD was not clearly stated, although it was mentioned that some life tables were taken from neighboring countries (Angola, Guinea-Bissau, ...)

[11] This model was also retained for São Tomé, for which no estimates were calculated in the 2000 revision due to the small population size.

sidered to obtain the most accurate levels of adult survival[12].

For the 2008 revision, the INDEPTH age pattern used in the 6 Western African countries cited above was replaced by a "Sahelian" pattern developed by Timaeus (1999)[13].

In contrast with previous revisions, the latest estimates updated in 2010 have not been further adjusted downwards. Benin, Côte d'Ivoire, Guinea, and Togo have been shifted back from the South to the North model, occasioning a large increase in adult mortality. The probability ${}_{45}q_{15}$ for the period 2000-2005 roughly doubled, as is the case in Liberia, which was switched back from the South to the West model[14]. To date, the South model is only retained for Chad, Malawi and São Tomé. The West model concerns Cape Verde, Comoros, Djibouti, Liberia, and 4 countries located in Southern Africa (Botswana, Lesotho, Namibia and Swaziland). Despite criticism, the North model thus remains the most widely used pattern, covering 25 countries, and all regions except Southern Africa.

2.1.2 Estimates of the number of orphans in childhood

UN agencies estimate the number of orphans from mathematical models relying on UNPD fertility and mortality rates (UNICEF 2006). The estimation method, developed by Grassly and Timaeus (2005), starts with the distribution of adult deaths by age and calendar year, and consists in estimating how many children were born to those adults, and whether these children are still alive and aged less than 18 years at the time of interest. To calculate the number of maternal orphans due to AIDS, the method accounts for the vertical transmission of the virus, the lower fertility of infected mothers, and the excess risks of mortality faced by orphans[15]. The HIV status of mothers in the years preceding their death is back-calculated, using a standard pattern of disease progression. The number of maternal orphans due to other causes than AIDS is calculated in a similar way, assuming that their mothers remain uninfected. The estimation of paternal orphans is further complicated by the need to account for the effect on child survival of HIV transmission (from mother to child and between parents), as well as the reduced fertility of partners of infected men. This is done by using DHS data on concordance of HIV status amongst heterosexual partners. Because data on male fertility are seldom collected, a standard schedule is applied to estimate the number of children who were born by age of fathers (Paget and Timaeus 1994). Finally, since survival chances of both parents are not independent, the excess risk of dual orphanhood is predicted from a multi-level model fitted on proportions of maternal,

[12] Additional changes for the 2006 revision concerned Tanzania (with a shift from South to North) and Chad (from North to South).

[13] Likewise, estimates for Sierra Leone were obtained with the Brass logit system using a "Western and Eastern Africa pattern" developed by the same author, and indexed with measures of adult mortality obtained from orphanhood, reported deaths and intercensal survival ratios. Liberia was also switched from West to South model, and the North model was adopted for Rwanda.

[14] In addition, the North model was adopted for Congo instead of the West model.

[15] Using data from demographic surveillance sites, Zaba et al. (2005) showed that, in addition to higher death rates due to mother-to-child transmission, children under age 5 of both infected and uninfected mothers experienced higher mortality risks in a 2-year period centered on the mother's death.

paternal and dual orphans observed in DHS[16].

This estimation method has been embraced by UNAIDS and incorporated within Spectrum in the AIM module used to predict the demographic impact of the HIV epidemic. This module is informed by recommendations of the UNAIDS Reference Group on Estimates, Models and Projections (Stover et al. 2008; 2010). It interacts with DemProj, the core module of Spectrum, which is a cohort component projection model based on the no-AIDS estimates (and projections) of the UNPD.

It should be mentioned that death rates underlying the Spectrum projections are not strictly equivalent to UNPD mortality estimates. Instead of using no-AIDS age-specific mortality rates from UNPD, Spectrum starts with life expectancies at birth from the no-AIDS scenario and combines them with model schedules of mortality. In most cases, the age patterns retained as default by Spectrum are those used by the UNPD. Therefore, in a majority of countries, background mortality rates should be roughly identical to WPP no-AIDS rates[17]. However, in 7 Western African countries where UNPD employed the two-parameter Brass logit system (Burkina Faso, Gambia, Mali, Mauritania, Niger, Senegal and Sierra Leone), the North model was the default pattern used in Spectrum[18]. Likewise, for Mauritius and Réunion, the WPP estimates were not based on model age patterns but on country-specific life tables[19]. For this reason, these 9 countries will not be considered in section 3 when comparing observed and Spectrum-based orphan prevalence. They are only taken into account in the comparisons with sibling estimates (when covered by the DHS program).

2.2 DATA ON KIN SURVIVAL AS A SOURCE OF MORTALITY ESTIMATES

To compile kin-based estimates of orphanhood and adult mortality, this study makes use of a variety of data sources. First, trends in probabilities ${}_{45}q_{15}$ from 1982 onwards are obtained from 64 DHS sibling histories collected in 32 countries from 1992 to 2010[20]. Secondly, proportions of orphaned children are derived from DHS surveys, MICS surveys, IPUMS micro-level census data, as well as census reports for 38 countries from 1965.

[16]The estimation of the excess risk of being double orphans has no bearing on this analysis, since we are only dealing with proportions of paternal or maternal orphans, irrespective of the survival status of the other parent.

[17]In South Africa, São Tomé and Chad, the default pattern used in the latest version of Spectrum was not the model used by the UNPD, but it was changed for this analysis.

[18]Expect in Sierra Leone, where the South model is retained.

[19]In these two cases, Spectrum uses the West model as default.

[20]Several DHS are discarded: the DHS conducted in Sudan in 1990 because the dataset is not standardized, the DHS for Nigeria 1999 because the data are not of very good quality (Pullum 2008), the data from the Ghana Maternal Health Survey 2007 because it is a special DHS with two successive fieldworks, and the DHS conducted in 1995 in Eritrea because the data is not in public domain.

2.2.1 Sibling survival data from Demographic and Health Surveys

Sibling histories have been collected in a maternal mortality module included in DHS surveys since 1988. A standardized set of questions is used to elicit an exhaustive list of siblings born to the same mother by birth order. Information is collected about their gender and survival status. Current age is recorded for surviving siblings, while age at death and years since death are collected for the deceased[21]. Some additional questions are aimed at identifying pregnancy-related deaths. In addition to interviews with women of reproductive ages, questions about sibling survival are included in the men's questionnaires of 10 African DHS on a subsample of households. Sibling histories are also collected in other international survey programs, such as the World Health Surveys and MICS surveys, but the data remain barely analyzed (Obermeyer et al. 2008).

The main advantage of sibling histories is that they provide direct estimates, since the observed number of deaths can be divided by the corresponding person-years of exposure. Indirect techniques are also available to convert proportions of surviving siblings into survival probabilities (Hill and Trussell 1977, Timaeus et al. 2001), but they tend to smooth out the trends in mortality. One limitation of the direct approach is that sample sizes do not allow for the calculation of annual age-specific death rates without introducing some modelling. Estimates presented in this paper are obtained from a Poisson regression model inspired by the work of Timaeus and Jasseh (2004). The regression equation is expressed as follows:

$$\begin{aligned} ln(\mu(x,g,i,t)) = \beta_0 + \beta_1(g,i) + \beta_2(g,i)t + \beta_3(i)(\bar{x},g) + \\ \left\{(\beta_4(i) + \beta_5(\bar{x},g))\,(t-T_i) + \beta_6(i)(t-T_i)^2 I(i \in S)\right\} I(t > T_i) I(x \geq 20) \end{aligned} \quad (1)$$

where x is an index for the age, $\bar{x}$ for the age group, g for the sex, i for the country and t for the year. The overall mortality level and sex differences are allowed to vary by country ($\beta_1(g,i)$), and the background mortality follows a log-linear trend with a country-specific rate of increase ($\beta_2(g,i)t$).

Timaeus and Jasseh (2004) introduced an set of external single-year mortality rates (close to the South model) to smooth death rates, but no model is included here, in order not to assume any age pattern. The age group is simply included as a set of dummy variables (by sex). However, ages at death are smoothed with cubic regression splines before fitting the model. This is because raw estimates are heavily distorted by the preference for round ages at death. As a result, death rates are often higher at ages 40-44 than at ages 45-49, and higher at ages 50-54 than at ages 55-59. Heaping on 60 is particularly problematic, because it shifts deaths occurring at ages 55-59 out of the age range considered. Smoothing of ages at death partly corrects for this.

In the regression, the age pattern of mortality is assumed to be specific to each country, but does not vary over time. An exception is made for countries whose HIV prevalence reached 1%. Four years after the HIV prevalence reaches this threshold (T_i), the level is

[21] In some surveys, the question "In what year did ... die?" is asked instead. Respondents are asked "How many years ago did ... die?" if they cannot remember the year of death.

allowed to change along with the duration of the epidemic ($\beta_4(t - T_i)$). Above age 20, the age pattern can also be modified, but in a similar way within each geographic subregion. To accommodate possible declines in adult mortality, a quadratic term is added for a subset of countries (S) with a stalling or decreasing HIV prevalence. The period under observation is limited to 11 completed years prior to the survey. This restriction is motivated by the decline of the number of siblings aged 15 to 59 reported by respondents aged 15 to 49 when the reference-period extends further back in time[22].

As is the case of all types of retrospective reports on kin survival, sibling histories are plagued with selection biases. Low mortality sibships are overrepresented because the experience of the respondent's siblings is counted multiple times when more than one sibling is interviewed. Some sibships are not sampled at all because no sibling survives or is eligible to the individual questionnaire. Gakidou and King (2006) proposed adjustments to correct for these biases. Recent attempts to apply these adjustments to DHS surveys (Obermeyer et al. 2008; 2010, Rajaratnam et al. 2010) artificially inflated mortality rates because they did not take into account the age and sex of respondents and siblings. Since no method of correction is fully satisfactory, I do not attempt to correct for selection biases, and make the critical assumption that mortality is not associated with sibship sizes (Trussell and Rodriguez 1990). An earlier examination of DHS data concluded that adult female mortality declined only slightly with the number of sisters surviving in adulthood. This pattern most likely stems from familial clustering of deaths or pervasive recall errors in large sibships. The decline of mortality with sibsize will lead to conservative estimates, but corrections for selection biases should amount to at most 5 to 10 percent (Masquelier forthcoming).

Previous research on sibling survival data demonstrated that respondents tend to underreport the death of their siblings (Timaeus and Jasseh 2004, Obermeyer et al. 2010, Reniers et al. 2011). A standard approach to assess the extent of such underreporting consists in comparing mortality rates from successive surveys when there is an overlap in reference periods. In 17 countries of sub-Saharan Africa, at least two sets of sibling histories have been collected in DHS separated by less than 10 years[23]. The time elapsed between the survey and each person-period is introduced as a set of dummy variables in the model described above, pooling together 40 DHS with overlapping periods. The estimated rate ratios are presented in Figure 3.

Figure 3 about here

Completeness of death reporting declines rapidly as the interval between their occurrence and the survey increases. Compared with 0 to 1 year immediately preceding the

[22]As in Timaeus and Jasseh (2004), the recall period in surveys conducted in Rwanda is limited to discard the period of the 1994 genocide.

[23]Burkina Faso, Cameroon, Ethiopia, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mozambique, Namibia, Uganda, Rwanda, United Republic of Tanzania, Chad, Zambia and Zimbabwe. This analysis is restricted to reports made by female respondents, because no country has conducted two DHS less than 10 years apart with sibling histories included in the male questionnaire.

survey (the referent level), male deaths are significantly underreported when they occurred as early as 3 completed years before the survey. There is also a distinct heaping on 10 (and on 5 to a lesser extent), which reflects that respondents have difficulty recalling how many years occurred since their siblings' death. When the reference period extends further than 5 completed years, completeness of death reporting for males drops to less than 75% (except for 10-11 years prior to the survey). The pattern is slightly different for sisters, for which the relative underreporting declines below 75% more than 7 completed years prior to the survey.

Unadjusted estimates will exaggerate the rate of mortality increases, and result in underestimates of mortality levels. To correct for this, adjustment factors are applied to the number of deaths according to the time between their occurrence and the survey. The inverse of the rate ratios presented in Figure 3 are used as correction factors for the period 0-11 completed years prior to the survey[24]. These adjustment factors also aim to correct for the heaping on 5 and 10 (albeit quite crudely). The resulting estimates of the probability ${}_{45}q_{15}$ are presented in Table 2 (p. 27). It should be kept in mind that this correction only concerns the *relative* underreporting. If the relative underreporting is so large, there is little doubt that even the most recent reports are incomplete as well (Timaeus and Jasseh 2004).

Owing to this poor quality of recall, the general consensus is that sibling histories can only provide lower bound estimates. For instance, using 14 DHS conducted between 1989 and 1995, Stanton et al. (2000) evaluated unadjusted probabilities of dying between ages 15 and 50 (${}_{35}q_{15}$) derived from sibling histories against life expectancies estimated in the 1994 Revision of the WPP. Then they compared the relationship between the two indexes of mortality with the corresponding relationship embodied in Princeton life tables. This assessment revealed that several sibling estimates fell well below the level that would be expected if the age pattern of mortality conformed to one of the mortality schedules. Supplementing this analysis with additional comparisons with independent estimates deemed to be of good quality, Stanton et al. (2000) concluded that sibling histories understated mortality, especially in sub-Saharan Africa, and that the downward bias was higher for females than for males.

A more recent assessment was made by Reniers et al. (2011), who juxtaposed sibling and UN estimates of the probabilities ${}_{45}q_{15}$, using the 2008 Revision of the WPP. They showed that discrepancies between both sets of estimates were larger in countries that are not severely affected by HIV, especially in some of the Sahelian countries (Niger, Senegal and Mali). They speculated about the reasons for this and suggested that the recall lapse could be more pervasive in Western Africa because of greater complexity of family structures (due to higher fertility rates and polygyny). Another plausible explanation is that sibling histories underestimate mortality irrespective of the region, but this is obfuscated in countries affected by HIV/AIDS, because UN estimates are themselves biased downwards

[24]For males, the adjustment factors are: 1 (referent level), 1.05, 1.05, 1.20, 1.25, 1.09, 1.42, 1.41, 1.41, 1.77, 0.84 and 2.00. For females, they are: 1, 1.03, 1.02, 0.99, 1.11, 1.03, 1.21, 1.33, 1.18, 1.64, 0.80 and 1.93.

in HIV settings. Pointing at refusal biases in DHS data as a possible source of underestimation of HIV prevalence, Reniers et al. (2011) concluded tentatively that the AIDS-mortality could be too low in recent model-based estimates. This line of inquiry is pursued in section 3.

2.2.2 Orphanhood data in censuses and surveys

The second type of kin survivorship statistics widely available in sub-Saharan Africa originates from data on parental loss. Information on the survival of biological parents has been collected in more than 135 nationally representative surveys and more than 65 censuses.

Questions about orphanhood were first included in retrospective surveys organized in Chad, West Cameroon and Mauritania in 1964-65, as well as in the mortality module administered in some of the World Fertility Surveys. They were aimed at allowing the indirect estimation of adult mortality through the orphanhood technique, a method originally proposed by Henry (1960) and refined, among others, by Brass and Hill (1973) and Timaeus (1986; 1991a;c;d; 1992). In the early 1990s, questions on orphanhood appeared in the DHS and MICS rosters of household members[25]. However, these questions were restricted to children under 15 (or 18), which indicates the focus had moved to the vulnerability of orphans and vulnerable children (OVCs).

Many African countries have also included these questions in their census schedule since the 1960s. Some countries have collected data on parental loss at each census round (e.g. Gambia, Kenya, Sierra Leone), while other countries have never done so (e.g. Guinea or Nigeria). As is the case of sample surveys, the primary purpose of these questions was to allow the estimation of adult mortality. Later on, the HIV-TB epidemic spurred a renewed interest in the number of orphans, their schooling attainments and living arrangements. In a few countries, questions on parental survival were then restricted to people under a certain age (18, 20 or 25).

This study draws on proportions of orphaned children under age 15 as observed in 40 censuses, 84 DHS, 41 MICS, and 19 additional surveys (such as *Sexual Behavior Surveys* in Zambia or *October Household Surveys* in South Africa). Maternal orphans are defined as children whose mother is dead, regardless of the survival status of their father. Paternal orphans are defined in a similar way. Because causes of death of parents are not recorded, it is not possible to distinguish between AIDS- and non-AIDS orphans.

It is widely recognized that observed proportions of orphans underestimate by a large extent the true orphan prevalence. The most pervasive problem is the "adoption effect", which refers to the fact that some fostered orphans are misclassified as non-orphans. In the presence of adults, interviewers may not probe whether they are the biological parents of children observed in the household (Blacker 1984). Foster parents may also deliberately

[25]In some of the first DHS, eligible women were also asked about the survival of their parents and parents-in-law, but it was rather to establish if they lived with their parents after marriage, in order to analyze the effects of residential patterns on fertility and contraceptive use (Timaeus 1991c).

or inadvertently claim adopted orphans as their own offspring. Often cited as a source of confusion is the usage of terms pertaining to biological parents to refer to larger circles of kins or to show respect to elders. In addition, many children in sub-Saharan Africa do not cohabit with their parents but are fostered in the extended family (Renata 2009).

From the outset, the adoption effect was identified as the main reason for the implausibly low levels of mortality calculated from young orphans, compared to those derived from older respondents (Blacker and Mukiza-Gapere 1988, Timaeus 1991b). The adoption effect is supposed to be more pronounced in reports relative to children, because they are less likely to know that they have been adopted, and because at older ages, both biological and foster parents are more likely to be dead. Methods were later developed to estimate mortality from orphanhood in adulthood or before and since marriage (Timaeus 1991a;c).

Two studies analyzed the consistency of reports on orphanhood status in successive inquiries. Pison and Langaney (1988) compared the reports collected during a census of the Fula Bande in Bandafassi (Eastern Senegal) in 1975 with a genealogical survey conducted subsequently. As much as 32% of fatherless children under age 15 were reported in the census as having their father alive. Quite surprisingly, Pison and Langaney (1985) noted that maternal orphans identified in the census were not mis-reported as having their mother alive. More recently, Robertson et al. (2008) analyzed the consistency of reporting of orphanhood status across successive rounds of a cohort study in Manicaland (Zimbabwe). They found that, out of 198 children reported as maternal orphans in the first round (and followed up to the third round), 33% were reported as non-orphans at least once in the next two rounds (with 95% confidence intervals ranging from 26.7 to 39.9). In contrast with what was observed in Senegal, the reports on parental survival appeared to be more consistent, since only 13.4% (10.9 - 15.9) of paternal orphans were later reported as having a living father. Higher consistency of reports on paternal orphanhood status could be explained by a higher likelihood of paternal orphans to live with their surviving mother (as compared with maternal orphans with their surviving father), as well as by higher remarriage rates among widowers.

In addition to the adoption effect, orphan prevalence can be biased by non-responses and age misreporting. Proportions of missing responses on orphanhood status are usually rather low, but they are of the same order of magnitude as proportions of orphans. Here, missing or unknown responses are simply discarded, under the assumption that ignorance of orphanhood status is not associated with the risk of being orphan (Beegle et al. 2010). Finally, ages reported in censuses and surveys are also plagued with inaccuracies, such as age exaggeration and attraction on round digits. Since round ages are located at the lower age limit of the 5-years age groups, age heaping is likely to result in net transfers in lower age groups. This will lead to further underestimating the proportions of orphans when tabulated by 5-years age groups.

The first systematic comparison between Spectrum-based and observed orphan prevalence was conducted by Grassly et al. (2004). The proportions of maternal orphans in MICS

and DHS were consistently lower than model predictions (by 40% on average), irrespective of the HIV prevalence. Paternal orphan prevalence was more in agreement with model outputs, with a closer congruence in countries with high HIV prevalence. Grassly et al. (2004) ascribed these discrepancies to a combination of (1) overestimation of background adult mortality by the United Nations and (2) underreporting of orphanhood status because of the adoption effect. Grassly et al. (2004) concluded that the North and West model were inappropriate, and showed that reducing adult mortality from causes other than AIDS would produce a closer agreement with survey data[26]. This work probably helped convince the UNPD to shift from the North to the South age pattern for a dozen African countries in the 2004 revision.

More recently, Robertson et al. (2008) presented ratios of Spectrum orphan prevalences over DHS estimates, for various countries of sub-Saharan Africa. Important discrepancies were again noted with the 2006 revision of the WPP, albeit less pronounced than observed with the 2000 revision. The proportions of fatherless children accorded closely with Spectrum estimates.

3 RESULTS

3.1 Descriptive statistics

To give an overall view of the differences between model-based and kin-based estimates, Table 3 presents 5% and 95% quantiles, means and standard deviations for the prevalence of orphanhood by age and type (between 1976 and 2010), as well as the life table probabilities ${}_{45}q_{15}$ (between 1981 and 2010).

Table 3 about here

On average, proportions of maternal orphans obtained from Spectrum are higher than those derived from surveys and censuses, but it is not the case of fatherless children under age 10. Differences between both series of estimates are particularly salient for the 5% quantiles, indicating either that Spectrum fails to predict accurately the lowest orphan prevalences, or that census and surveys can provide implausibly low levels. For maternal orphans, the dispersion around the mean is slightly larger in Spectrum outputs. By contrast, the standard deviations computed from paternal survival data are almost twice as large as those computed from the model. This is expected, because the estimation of paternal orphan rates requires additional information about male fertility and concordance of parental HIV status. The use of a single fertility age pattern for males probably accounts for some of the underestimation of the variability of paternal orphan prevalence. However, the difficulty to model paternal orphanhood is not the whole problem, since there is also a lower variation in UNPD estimates of the probability ${}_{45}q_{15}$, particularly for males. The

[26] At that time, model projections were based on the West pattern of Princeton life tables (UNAIDS 2002), in conjunction with life expectancies of the 2000 revision of the WPP. These life expectancies were themselves mostly obtained by indexing the North model with levels of child mortality.

mean values of UNPD estimates are higher, but the variation around the mean is larger when computed from sibling histories. Also notable is the difference between the 95% quantile of the probability ${}_{45}q_{15}$ for males obtained from DHS (0.66) and the same quantile for UNPD estimates (around 0.58).

The upper panel of Figure 4 compares orphan prevalence among 5- to 9-year-olds recorded in surveys and censuses with the corresponding Spectrum outputs (for the period 1976-2010). The lower panel displays a comparison between probabilities of dying in adulthood (${}_{45}q_{15}$) derived from sibling histories and the corresponding UNPD ${}_{45}q_{15}$ for the beginning of calendar years from 1983 to 2008 by 5-year increments[27]. Estimates for which the sex-specific HIV prevalence exceeded 5% are indicated in black. Because there is a lag between rises in HIV prevalence and increases in the number of AIDS-related deaths and AIDS orphans, the HIV prevalence refers to 5 years prior to the survey or census. The prevalence of HIV is obtained from Spectrum, because estimates distributed by UNAIDS are not broken down by sex.

Figure 4 about here

The agreement between both series of estimates clearly varies by sex, with higher correlation coefficients in the case of female mortality (≥ 0.7). A second observation is that more estimates relative to fathers and brothers lie above the equivalence straight line than is the case for mothers and sisters. This indicates that sex differentials of adult mortality observed in surveys and censuses are larger than those embodied in model-based estimates. For orphan prevalence, this pattern can be ascribed to more pervasive misreports when information is elicited about the survival of mothers, owing to the adoption effect. But in the case of siblings, this cannot be readily explained by differential underreporting of deaths by sex. Completeness of death reporting declines more rapidly for brothers as the reference period extends further back in time, denoting a lower level of recall. A third observation is that the higher male mortality from data on close relatives is particularly conspicuous in settings where HIV prevalence reached 5%. By contrast, Spectrum estimates of the fraction of children who lost their mother are consistently higher than kin-based estimates, irrespective of the female HIV prevalence. The ratios between UNPD probabilities ${}_{45}q_{15}$ and those derived from the survival of sisters also seem to be less related to HIV prevalence than is the case with brothers.

The average ratio of modeled to observed proportions of children who lost their mother (also called MAPE for mean absolute percentage error[28]) equals 149% for children under

[27] Those are the mid-points of each five-year period. For example, the period 2005-2010 begins on July 1, 2005 and ends on June 30, 2010. January 1, 2008 is the midpoint of the period and the estimate is assumed to refer to this date.

[28] This measure can be computed as:

$$100 \times \frac{1}{n} \sum_{t=1}^{n} |\frac{f_t}{a_t}| \tag{2}$$

where f_t is the model-based estimate and a_t is the observed proportion of children orphaned (Swanson et al. 2011).

age 15. Overall, this value ties in with the magnitude of the adoption effect estimated in Eastern Zimbabwe by Robertson et al. (2008) among children under 16 years. If one third of motherless children are reported as non-orphans, the 'true' orphan prevalence should be about 149% higher than the observed prevalence (in the absence of other errors). Similarly, if 13% of paternal orphans were reported as non-orphans (as was noted in Zimbabwe), the ratio of Spectrum-based to observed proportions of paternal orphans should be about 115%, assuming again that discrepancies stem solely from declaration errors. This is very close to the MAPEs computed for paternal orphans (113%), although Figure 4 shows that part of this better agreement is due to an underestimation of orphan prevalence in countries with high mortality and HIV prevalence.

Ideally, ratios of modeled to observed proportions of orphans should remain fairly constant with HIV prevalence, because there is no obvious reason why the adoption effect should vary with the magnitude of the epidemic. These ratios should also decline with age since younger children are more likely to report a deceased parent as surviving (Robertson et al. 2008).

Contrary to our first expectation, ratios tend to decrease with HIV prevalence, especially for fathers. Among paternal orphans aged 10 to 14, the MAPE equals 129% when male HIV prevalence does not exceed 5%, but it drops to 96% in high prevalence countries. The decline is less steep for mothers, with a change in the MAPE from 166% to 137% in the same age group. The agreement between both types of estimates is also distinctly related to the observed level of orphanhood, with lower ratios when observed prevalence is higher. This is shown in Figure 5, with displays ratios with two horizontal lines at 149% (for mothers) and 115% (for fathers) as benchmarcks. The age group 10 to 14 is chosen because it offers a particularly egregious example of discrepancies between both types of estimates. Percentage errors also decline slightly with the level of background life expectancy at birth.

Figure 5 about here

For both sexes, ratios tend to increase as children get older when the HIV prevalence has remained low, which is not in line either with our expectations. The MAPE equals 140% for maternal orphans under 5, versus 166% above age 10. By contrast, in settings where HIV prevalence was higher than 5%, ratios decrease slighlty as children get older: from 158% on average for maternal orphans under 5 to 137% when they reach age 10.

A series of Wilcoxon signed-rank tests indicates that modeled proportions of maternal orphans are significantly higher than observed proportions, irrespective of the age group and the level of female HIV prevalence (p-val. < 0.001). According to Bartlett's tests of homogeneity of variances, variances of observed proportions do not differ significantly from those of the modeled proportions[29]. For fathers, model proportions are significantly higher than observed proportions only in settings with low HIV prevalence and for children above age 5. In contrast to the common belief that census and survey underestimate the true orphan prevalence, model outputs for children under age 10 are not statistically different

[29]Except for children under age 5 in low HIV settings, where the dispersion in model outputs is larger.

from observed proportions in high HIV settings. Proportions of fatherless children aged 10 to 14 are even significantly *higher* than model outputs when male HIV prevalence reaches 5% (p-val. < 0.05), and this points to some underestimation by Spectrum. As noted earlier, variances of observed proportions for fathers are significantly larger than variances of model outputs, regardless of the age group and prevalence of HIV.

Considerable differences in the agreement between both series of estimates also exist according to the model schedules used to infer background mortality. For orphans above age 5, MAPEs are highest when the West model is used if HIV prevalence has remained below 5%[30]. For example, for maternal orphans aged 10-14, MAPEs are respectively 144, 167 and 191% for the South, North and West models. However, when HIV prevalence exceeds 5%, a different pattern is observed: the MAPE for the West model is only 100%, against 151% for the North model and 127% for the South model (mainly because of Malawi since the South model concerns only Chad, Malawi and Sao Tomé). For paternal orphans of the same age in high HIV settings, the MAPE declines as low as 60% when the West model is employed. This does not imply that the West model necessarily results in underestimates in high HIV settings, because the choice of the age pattern is partly regional. While the North model is employed in all regions, the West model is retained in all countries in Southern Africa (except South Africa). Southern Africa is experiencing the highest HIV prevalence, and benefiting from the lowest non-AIDS mortality rates. Therefore, variations in MAPEs according to model schedules of mortality could reflect regional variations in HIV prevalence and background mortality.

We now turn to descriptive statistics for the life table probabilities ${}_{45}q_{15}$.

As is the case with orphanhood, ratios of UN to sibling estimates are lower in high HIV settings, especially among males. They decline from 124% to 94% when the lagged male HIV prevalence exceeds 5%. For females, they decrease from 137 to 118%. According to Wilcoxon signed-rank tests, DHS estimates are significantly lower than UNPD estimates when HIV prevalence remains below 5%, but significantly higher when HIV prevalence exceeds this threshold.

MAPEs computed from the probabilities ${}_{45}q_{15}$ vary with the model schedule of background mortality. In low-HIV settings, they are again the highest when the West model (and Far Eastern model) are retained for females (164% and 189%), as was the case with orphan rates. They are the lowest when the South model is employed (113%)[31]. For males, the highest values are obtained with the Brass logit model (141%, against 111% with the South model). MAPEs are much lower when HIV prevalence is above 5%, especially when computed from estimates obtained from the West model (as low as 79% for males against 99% with the North model).

[30] Among young orphans aged 0-4, the Far Eastern pattern always results in the lowest MAPEs (but it is based only on South Africa and Eritrea), followed by the West model. For the latter, available estimates concern Botswana, Cape Verde, Comoros, Djibouti, Lesotho, Liberia, Namibia and Swaziland.

[31] Countries with sibling data in which the South model is used by the UNPD are Chad, Malawi and Sao Tomé. Countries with sibling data in which the West model is used are Lesotho, Liberia, Namibia and Swaziland.

In addition, there is a large variation in the congruence of UN estimates with DHS data when the ratios are broken down by age group (Fig. 6). Overall, when HIV prevalence has remained under 5%, the ratios are fairly constant with age among 20- to 55-year-olds, with MAPEs ranging from 150 to 160%. They are lower for the first and last age groups (respectively 116 and 138%). By contrast, in high HIV settings, MAPEs for females first increase rapidly with age (from 80% for 15- to 19-year-olds to 170% for 30- to 34-year-olds), and then drop as low as 77% for 50- to 55-year-olds. This cannot be attributed entirely to mistatements of siblings' age, because this pattern should then be apparent in low HIV prevalence countries as well. Rather, this suggests that age patterns of mortality increases due to AIDS derived from sibling histories differ from those embodied in United Nations estimates. According to sibling data, the "AIDS hump" is wider; women aged 15-24 and women aged 45-59 experience higher mortality rates than currently assumed in countries with generalized HIV epidemic, while mortality rates faced by 25- to 35-year-olds are lower. To a lesser extent, the AIDS-hump in male mortality rates also appears to be less concentrated at ages 25-39 than implied by model-based estimates, with higher death rates among middle-aged adults.

Figure 6 about here

A striking example of differences in age patterns of mortality is the case of Zimbabwe, which is presented in the upper panel of Figure 7. This figure juxtaposes sibling estimates for the year 1998[32] with death rates produced for the WPP2010 for the period 1995-2000. Estimates obtained by Feeney (2001) from adjusted registration of deaths (for 1995) and recent deaths reported in the Intercensal Population Survey (for 1997) are overplotted. When compared solely with UNPD estimates, one could think that sibling estimates fail to accurately capture mortality increases due to AIDS. The high peak in female death rates between ages 25 and 40 is not as protruding in DHS data. Rather, mortality rates increase steadily until age 30 before reaching a plateau. The UNPD probability ${}_{45}q_{15}$ for females is only 15% higher than the same probability from DHS, but the number of female deaths and the number of maternal orphans are likely to be much larger with the pattern implied by the UNPD. According to reports on brothers, there is no decline with age either among males (at least before age 60); death rates keep increasing consistently and very rapidly, overtaking UN death rates around age 40. The values of the probability ${}_{45}q_{15}$ for males are roughly equivalent, but the age patterns differ markedly. Interestingly, estimates from Feeney (2001) are more in line with DHS estimates than with UN estimates. They are only a little lower, but this is consistent with the fact that they refer to earlier periods than 1998. For both sexes, the sibling death rates predicted for 1995 agree well with those derived from adjusted civil registration (results not shown here).

Figure 7 about here.

Observations made with data from Zimbabwe may not hold in countries with lower HIV prevalence. For example, it is not as clear-cut in Tanzania, where HIV prevalence was

[32]Derived from DHS conducted in 1994, 1999, 2003 and 2006, with corrections for underreporting of deaths in the distant past and smoothing of ages at death with cublic splines.

estimated at 7.7% in 1998, against 26.3% in Zimbabwe (2010 UNAIDS Report). The lower panel of Fig. 7 displays age-specific risks of dying alongside estimates from 5 demographic surveillances sites maintained in the country (INDEPTH 2002). Some of them are in accord with DHS death rates, while others are closer to UNPD estimates. The "AIDS hump" is not apparent in DHS and very pronounced in UNPD estimates, especially for females. In Morogoro and Rufiji, there is a distinct hump followed by a decline and then an increase in the last age groups, very similar to model outputs. In the urban site of Dar es Salaam, the female mortality rates also increase rapidly and then reach a plateau at age 30. By contrast, in Ifakara and Hai, risks of dying are closer to DHS estimates.

Among males, with the possible exception of Dar es Salaam, DSS estimates do not present the age hump prior to age 45 that is present in UNPD estimates. Here too, the mortality increase due to AIDS could be more distributed among the adult ages than implied by model-based estimates.

3.2 Linear mixed-effects models

To investigate further the patterns of discrepancies between both types of estimates, two linear mixed-effects models are used, allowing for variations at the country level. The same model is fitted first on ratios computed from proportions of orphans and then on ratios computed from adult mortality rates. The logged ratios of model-based to kin-based estimates serve as dependent variables. This ensures the focus is on percentage changes instead of absolute differences and allows to merge all age groups and both sexes in the same model.

The regression model for orphanhood prevalence is expressed as follows:

$$\begin{aligned} ln\left[\frac{{}_5\pi_x^{\text{model}}(g,i,t)}{{}_5\pi_x^{\text{obs.}}(g,i,t)}\right] &= \beta_0 + \beta_1(i) + \beta_2(g,x) + \beta_3(t) + \beta_4(g,x)\text{HIV} + \beta_5(g,x)\text{LT} \\ &\quad + \beta_6(g,x)e_0 + \beta_7\text{TYPE} \\ &\quad + \beta_8 e_0 \times \text{HIV} + \beta_9 e_0 \times \text{LT} \\ &\quad \beta_1(i) \sim \mathcal{N}(0,\sigma_\beta^2) \end{aligned} \tag{3}$$

where ${}_5\pi_x(g,i,t)$ denotes the fraction of children who are orphaned, by sex of parents g, age group x, country i and calendar year t (centered on 1990). HIV is the sex-specific lagged prevalence obtained from Spectrum, LT is the age pattern retained by the UNPD to model background mortality[33], and TYPE refers to the data source (DHS, MICS, census or other survey). The life expectancy at birth in the no-aids scenario (e_0) is entered as a predictor, centered around its mean, and scaled by dividing by 1 standard error. $\beta_2(i)$ are random intercepts at the country level[34]. Contrasting this model with another one without random effects (via -2 log likelihood values) confirms there is a significant intercept variation (p-val. < 0.001).

[33]Estimates from Eritrea and South Africa are not included in this model because those are the only two countries for which the Far Eastern pattern was used.

[34]The model is fitted with the `nlme` function from the package *Linear and Nonlinear Mixed Effects Models* of the R statistical software

Fixed-effects parameter estimates are presented in Table 4 (p. 29), and summarized in the form of predicted ratios in Figure 8[35]. In the absence of HIV-AIDS, ratios of modeled to observed orphan prevalence rise with the age of children. They are significantly lower in the case of paternal orphans in all age groups. Compared with the majority of estimates which are derived from the North model, ratios tend to be slightly lower when the West model is utilized in low-HIV settings, but they increase more rapidly with HIV prevalence. This is in contrast with what was observed before controlling for the no-AIDS life expectancy. There is also a large gap between the South and the North model above age 5, but this is based only on 3 countries and 5 point estimates.

When the North model is used (i.e. for most countries), ratios decrease with HIV prevalence above age 5 and for all categories of paternal orphans. The rate of decline accelerates with age and it is a little larger for paternal orphans. This suggests that the adoption effect could be less pervasive in HIV-affected countries. This would happen if the practice of fostering was more common in countries with low HIV prevalence. However, the reverse is true; children (orphans and non-orphans) are less likely to live with their (surviving) parents in Southern Africa, which is by far the area most affected by the epidemic (Monasch and Boerma 2004). Therefore, another explanation has to be found. Another reason could be that recent downward adjustments to HIV prevalence have been too large. Refusal biases in DHS surveys could lead to an underestimation of HIV prevalence and an overestimation of female-to-male ratio of infection (Reniers and Eaton 2009).

Increases in the background life expectancy result in significant declines in the ratios (irrespective of the age group and the sex of parents). This decline is steeper when the West model is used to infer background mortality. As we noted previously, when the life expectancy increases, adult mortality rates provided by the West model are progressively lower than those of the North model, and the difference is more pronounced for males (see Fig. 2, p.34). In addition, the background mortality estimated by the UNPD is lower in countries with high HIV prevalence when the West model is retained, compared with other countries with similar levels of HIV prevalence and other age patterns. For instance, for the period 2005-2010, the average life expectancy at birth in the no-AIDS scenario for Namibia, Lesotho, Swaziland and Botswana was about 5 years higher for males and 4.5 years higher for females than the average background life expectancy in South Africa, Zimbabwe, Zambia and Malawi.

This decline of the ratios between observed and modeled orphan rates with no-aids life expectancy at birth is partly compensated by higher HIV prevalence (on average) for maternal orphans when the West model is used, but not for paternal orphans above age 5.

Figures 8 and 9 about here

Some of the observations made from orphan data also hold for sibling histories. The

[35]The upper panel of Figure 8 is based on a life expectancy at birth in the no-AIDS scenario of 56 years (the mean value observed in the sample), while the lower panel is based on an HIV prevalence of 0.

regression equation for adult mortality rates is expressed as follows[36]:

$$\begin{aligned} ln\left[\frac{{}_5q_x^{\text{UN}}(g,i,t)}{{}_5q_x^{\text{DHS}}(g,i,t)}\right] &= \beta_0 + \beta_1(i) + \beta_2(g,x) + \beta_3(t) + \beta_4(g,x)\text{HIV} + \beta_5(g,x)\text{LT} \\ &\quad + \beta_6(g,x)e_0 + \beta_7 e_0 \times \text{HIV} + \beta_8 e_0 \times \text{LT} \\ &\quad \beta_1(i) \sim \mathcal{N}(0,\sigma_\beta^2) \end{aligned} \tag{4}$$

Coefficients are presented in Table 5 (p. 32), with females aged 25-29 as referent level. To simplify the interpretation of coefficients, fixed-effects parameter estimates are displayed as predicted ratios in Figure 9. In the absence of HIV-AIDS, age patterns of deviation from sibling estimates are relatively similar across model schedules, with lower ratios at the two extreme age groups (15-19 and 55-59), as well as a trough in the curve around age 35 for males. The use of the West model leads to higher ratios for females in the absence of HIV-AIDS (unlike what is observed with orphan rates after controls), while the South model is associated with lower ratios for both sexes. As HIV prevalence increases, ratios decline at the tails of the age range, resulting in a pronounced concavity of the age pattern of deviation, as illustrated in Fig. 9 with an HIV prevalence of 10%. Unlike orphan rates, ratios tend to decline more rapidly with HIV prevalence in countries where the West model is retained, especially for males. This difference with orphanhood data deserves further examination. Patterns of discrepancies are probably less evident in the case of orphan rates, because changes in the survival chances of parents can be obfuscated by offesting changes in infant and child mortality[37]. However, what is consistent with orphanhood data is that increases in the non-AIDS life expectancy result in decreases in the difference between UNPD and DHS estimates. Ratios reach the lowest values for males around age 40. They also decline more rapidly with no-AIDS life expectancy when the West model is used.

Overall, the use of census and survey estimates as lower bounds suggests that adult mortality could be underestimated in countries with the highest HIV prevalence and the lowest background mortality, especially for males. This is particularly problematic in countries in Southern Africa where the West model is used to infer background mortality, partly because of this age pattern in itself, and partly because their life expectancy in the no-AIDS scenario is quite high. Figure 10 presents comparisons for 8 countries where HIV prevalence has been the highest. In the 4 countries on the left, the Far Eastern (South Africa), North (Zimbabwe and Zambia) and South models (Malawi) are used. Although there seems to be some underestimation of mortality in these countries, not all sources of kin survival data are consistent. For instance, in South Africa, paternal orphan prevalence

[36]Once again, comparing -2log likelihood values between this model and another model without random intercept reveals that the intercept variation is significant (p-val. < 0.001).

[37]For instance, a change in the model schedule of mortality will indirectly affect the proportions of orphaned children through the mortality of orphans. On the one hand, both orphans and non-orphans are exposed to the same level of mortality, hence an increase of mortality due to a change in age pattern will modify both the numerator and the denominator by the same factor. But orphans are also exposed to an excess mortality associated with the loss of their mother. If the maternal death occurs earlier, as is the case in patterns with an higher adult mortality, the depletion of the cohort of orphans is larger because the excess mortality is larger (a common factor is multiplied by higher risks of dying).

is higher than Spectrum results, while mortality rates estimated from siblings are much too low. There is a good agreement between sibling estimates and UNPD estimates in Zimbabwe when using the summary index ${}_{45}q_{15}$, whereas maternal orphan rates are lower than Spectrum estimates and paternal orphans are higher. Interestingly, this could be explained by differences in the age pattern of mortality between UNPD and sibling estimates, since a more pronounced AIDS hump among younger mothers will generate more orphans. In Zambia and Malawi, orphan rates are either lower or equivalent to Spectrum estimates for both sexes, while sibling estimates are higher for males after 1990 and lower in the more recent period for females.

By comparison, in the 4 countries on the right (Botswana, Lesotho, Namibia, and Swaziland), both types of kin-based estimates are consistent. Observed fractions of orphaned children are in line with UNAIDS estimates, which indicates that the latter are underestimates, because of the adoption effect. Paternal orphan rates are much higher than Spectrum outputs, sometimes almost twice as high. After 1995, probabilities ${}_{45}q_{15}$ calculated from sisters' survival are very close to UNPD estimates, which, again, suggests that the UNPD could underestimate mortality (considering the poor reporting of deaths in sibling histories). Data on brothers' survival yield higher ${}_{45}q_{15}$ than UNPD estimates.

Figures 10 and 11 about here

Finally, with regard to the debate about the choice of age pattern in low mortality countries, it appears that the shift from the South to the North model for the 2010 revision was timely, albeit not entirely satisfactory. For 4 countries in which the South pattern was discarded in the revision 2010, Figure 11 presents comparisons with estimates from the 2008 and 2010 revision. In the 2008 Revision, the probabilities ${}_{45}q_{15}$ obtained from siblings were almost everywhere higher than UNPD estimates, and orphan rates were roughly identical to UNAIDS estimates, which is unlikely. The shift to the North model occasioned a jump in probabilities ${}_{45}q_{15}$ and in orphan rates, perhaps a little too high. The true level of mortality probably lies somewhere between both sets of estimates. This large change, almost entirely attributable to a different model age pattern, is a good illustration of the need to adopt another method than the child-mortality matching approach. The UNPD recently initiated this change by using the Brass logit model for some countries in Western Africa.

4 CONCLUSION

In this paper, I showed that the extent to which model-based and kin-based estimates agree with one another varies greatly with the level of HIV prevalence, the model schedule used to infer background mortality, and the life expectancy of the no-aids scenario. In particular, I pointed to a few countries in Southern Africa where adult mortality is manifestly underestimated, either because HIV prevalence is too low, or because the mortality of the uninfected population is too low. Another significant result concerns sex differentials of adult mortality, which are larger in survey and census data than in model-based estimates.

In addition, the age pattern of mortality increase due to AIDS observed in sibling histories differ from the one embodied in UN estimates. One important difference between the two sets of estimates is that the modelling of AIDS mortality by the UNPD is based on the assumption of a constant age pattern of incidence[38]. However, during the course of the HIV epidemic, the "AIDS hump" of mortality is expected to broaden and gradually shift towards older ages (Sharrow and Clark 2010). In the coming years, this shift will be mainly driven by a reduction of mortality following the increasing availability of antiretroviral treatments, and the aging of the infected population, which are both taken into account in models. But even prior to ART, such changes can be steered by modifications in the age profile of HIV incidence. Little literature exists on the possible modifications in the age profile of new infections as the epidemic matures. In Uganda and Zimbabwe, behavioral changes have been shown to be particularly pronounced amongst younger adults, resulting in differential declines in HIV prevalence (Kilian et al. 1999, Gregson et al. 2006). In Uganda, both cohort studies and data from voluntary counseling and testing (VCT) have documented a shift of peak infection rates among middle-aged adults (Shafer et al. 2008, Baryarama et al. 2007). An on-going analysis of several DSS sites from the ALPHA network even suggests that secondary peaks in HIV incidence could be emerging (Zaba et al. 2008). One potential explanation for this is the remarriage of widows, which exposes older adults to higher risks of infection due to discordant partnership (Lopman et al. 2009).

Overall, although many orphans are misclassified as non-orphans, and sibling histories are plagued with underreporting of deaths, both sources of data provide useful lower bounds. Despite their limitations, they can yield insights into the trends in mortality that cannot be obtained from child survival and the modelling of AIDS mortality. Sibling data could even be capturing mortality increases due to AIDS more precisely than model-based estimates in the countries hardest hit by the epidemic.

5 ACKNOWLEDGEMENTS

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[38]This can be changed in Spectrum when data are available.

Table 1 – *Classification of model life tables used in successive revisions of the World Population Prospects to derive background mortality rates, and probabilities* ${}_{45}q_{15}$ *(both sexes) estimated or projected for 2000-2005*

Model age pattern	2000	2002	2004	2006	2008	2010
Princeton life tables						
North	25	33	22	19	20	25
South	1	0	11	8	8	3
West	3	6	9	9	8	8
UN life tables						
Far Eastern	0	2	2	2	2	2
Chilean model	1	0	0	0	0	0
Brass logit system						
Indepth-1	0	0	0	6	0	0
Sahelian pattern	0	0	0	0	6	6
West. and East. Africa pattern	0	0	0	0	1	1
Other						
Not based on child survival	9	4	2	2	2	2
Not stated	7	2	1	1	0	0
All causes ${}_{45}q_{15}$ for 2000-2005						
Eastern Africa	0.54	0.58	0.52	0.47	0.43	0.43
Middle Africa	0.44	0.52	0.49	0.43	0.38	0.4
Southern Africa	0.62	0.62	0.6	0.5	0.48	0.5
Western Africa	0.41	0.43	0.44	0.36	0.36	0.39
Sub-Saharan Africa	0.48	0.52	0.49	0.42	0.4	0.41

Source: United Nations (2001; 2003; 2005a; 2007; 2009a) and Luy (2010).

Table 2 – *Fitted values of the probability of dying between ages 15 and 60 ($_{45}q_{15}$) obtained from DHS sibling histories*

	Males				Females			
Country	1990	1995	2000	2005	1990	1995	2000	2005
Benin	0.31	0.33	0.33	0.31	0.21	0.22	0.22	0.20
Burkina Faso	0.39	0.40	0.37		0.27	0.28	0.26	
Cameroon	0.31	0.38	0.42		0.19	0.26	0.32	
CAR	0.49				0.41			
Chad	0.30	0.30	0.30		0.23	0.24	0.25	
Congo		0.63	0.58	0.28		0.45	0.43	0.20
Cote d'Ivoire	0.42	0.47	0.49	0.46	0.27	0.32	0.33	0.31
DR Congo		0.36	0.43	0.39		0.26	0.32	0.28
Ethiopia	0.43	0.47	0.39		0.31	0.38	0.33	
Gabon	0.38	0.39	0.40		0.29	0.29	0.28	
Guinea	0.24	0.28	0.33		0.24	0.26	0.28	
Kenya	0.24	0.36	0.42	0.41	0.19	0.28	0.33	0.31
Lesotho	0.18	0.39	0.66	0.75	0.10	0.24	0.47	0.59
Liberia		0.24	0.31	0.28		0.19	0.27	0.26
Madagascar	0.38	0.34	0.31	0.29	0.30	0.27	0.24	0.22
Malawi	0.31	0.52	0.62	0.58	0.30	0.48	0.55	0.48
Mali	0.28	0.29	0.31	0.32	0.35	0.32	0.30	0.28
Mozambique	0.26	0.32	0.40		0.22	0.26	0.31	
Namibia	0.35	0.43	0.53	0.64	0.18	0.25	0.34	0.46
Niger	0.29	0.27	0.25	0.23	0.28	0.25	0.23	0.20
Nigeria		0.25	0.34	0.31		0.21	0.29	0.27
Rwanda		0.75	0.57			0.49	0.43	
Sao Tome & P.		0.25	0.26	0.26		0.15	0.17	0.19
Senegal	0.29	0.27	0.26		0.24	0.22	0.21	
Sierra Leone		0.27	0.34	0.35		0.22	0.27	0.28
South Africa	0.31	0.38			0.15	0.19		
Swaziland		0.35	0.68	0.69		0.20	0.51	0.60
Togo	0.26	0.30			0.23	0.25		
Uganda	0.48	0.55	0.53	0.45	0.35	0.41	0.41	0.35
UR Tanzania	0.30	0.40	0.43	0.39	0.23	0.31	0.34	0.31
Zambia	0.43	0.64	0.69	0.59	0.36	0.54	0.60	0.50
Zimbabwe	0.32	0.51	0.65	0.72	0.23	0.38	0.53	0.62

Note: The inverse of the rate ratios associated with the time prior to the survey are used as correction factors. Estimates are derived from both women's and men's reports. Ages at death are smoothed with cubic regression splines between ages 10 and 64 before fitting the model.

Table 3 – *Descriptives statistics for the prevalence of orphanhood (38 countries between 1976 and 2010) and life table probabilities* ${}_{45}q_{15}$ *(32 countries between 1981 and 2010)*

	Kin-based estimates				Model-based estimates			
	5%	95%	Mean	SD	5%	95%	Mean	SD
Maternal orphanhood								
0-4	0.60	2.10	1.10	0.50	0.80	2.70	1.50	0.60
5-9	1.60	7.00	3.60	1.70	2.60	9.10	5.10	2.10
10-14	2.80	13.30	6.50	3.20	5.00	15.90	9.20	3.40
Paternal orphanhood								
0-4	1.40	8.30	3.70	2.20	2.00	5.40	3.30	1.10
5-9	3.70	17.60	8.50	4.60	5.20	13.60	8.50	2.50
10-14	6.60	29.0	13.60	6.30	9.20	21.0	14.10	3.50
Adult mortality (${}_{45}q_{15}$)								
Females	0.145	0.533	0.290	0.107	0.225	0.546	0.355	0.092
Males	0.223	0.656	0.375	0.129	0.279	0.580	0.406	0.082

Table 4 – *Fixed-effects parameter estimates for the regression of the logged ratios of modeled to observed prevalence of orphanhood*

Var	Coef	exp(Coef)	Std.Error	p.value	sign
(Intercept)	0.268	1.308	0.067	0.000	***
Maternal(0-4)	-0.007	0.993	0.038	0.854	
Paternal(0-4)	-0.387	0.679	0.044	0.000	***
Maternal(10-14)	0.113	1.120	0.038	0.003	**
Paternal(10-14)	-0.201	0.818	0.044	0.000	***
Paternal(5-9)	-0.259	0.772	0.044	0.000	***
HIV	-0.005	0.995	0.006	0.384	
E0	-0.235	0.791	0.032	0.000	***
South	-0.195	0.822	0.185	0.298	
West	0.399	1.490	0.143	0.009	**
Year	0.008	1.008	0.003	0.003	**
Census	0.073	1.076	0.026	0.004	**
MICS	0.032	1.032	0.025	0.195	
Other	-0.114	0.892	0.050	0.022	*
Maternal(0-4):HIV	0.009	1.009	0.004	0.025	*
Paternal(0-4):HIV	0.001	1.001	0.005	0.902	
Maternal(10-14):HIV	-0.013	0.987	0.004	0.001	**
Paternal(10-14):HIV	-0.029	0.972	0.005	0.000	***
Paternal(5-9):HIV	-0.017	0.983	0.005	0.000	***
HIV:E0	0.005	1.005	0.003	0.094	.
Maternal(0-4):South	0.038	1.039	0.086	0.657	
Paternal(0-4):South	0.177	1.194	0.088	0.044	*
Maternal(10-14):South	0.032	1.033	0.086	0.705	
Paternal(10-14):South	0.190	1.209	0.088	0.032	*
Paternal(5-9):South	0.166	1.181	0.088	0.059	.
Maternal(0-4):West	-0.328	0.721	0.081	0.000	***
Paternal(0-4):West	-0.513	0.599	0.087	0.000	***
Maternal(10-14):West	-0.008	0.992	0.081	0.925	
Paternal(10-14):West	-0.211	0.810	0.087	0.016	*
Paternal(5-9):West	-0.295	0.744	0.087	0.001	***
E0:South	-0.161	0.851	0.072	0.025	*
E0:West	-0.188	0.828	0.062	0.003	**
Maternal(0-4):E0	-0.026	0.974	0.031	0.396	
Paternal(0-4):E0	-0.009	0.991	0.031	0.767	
Maternal(10-14):E0	0.001	1.001	0.030	0.972	
Paternal(10-14):E0	-0.016	0.984	0.031	0.608	
Paternal(5-9):E0	-0.012	0.988	0.031	0.695	
HIV:South	0.032	1.032	0.012	0.007	**
HIV:West	0.006	1.007	0.004	0.141	

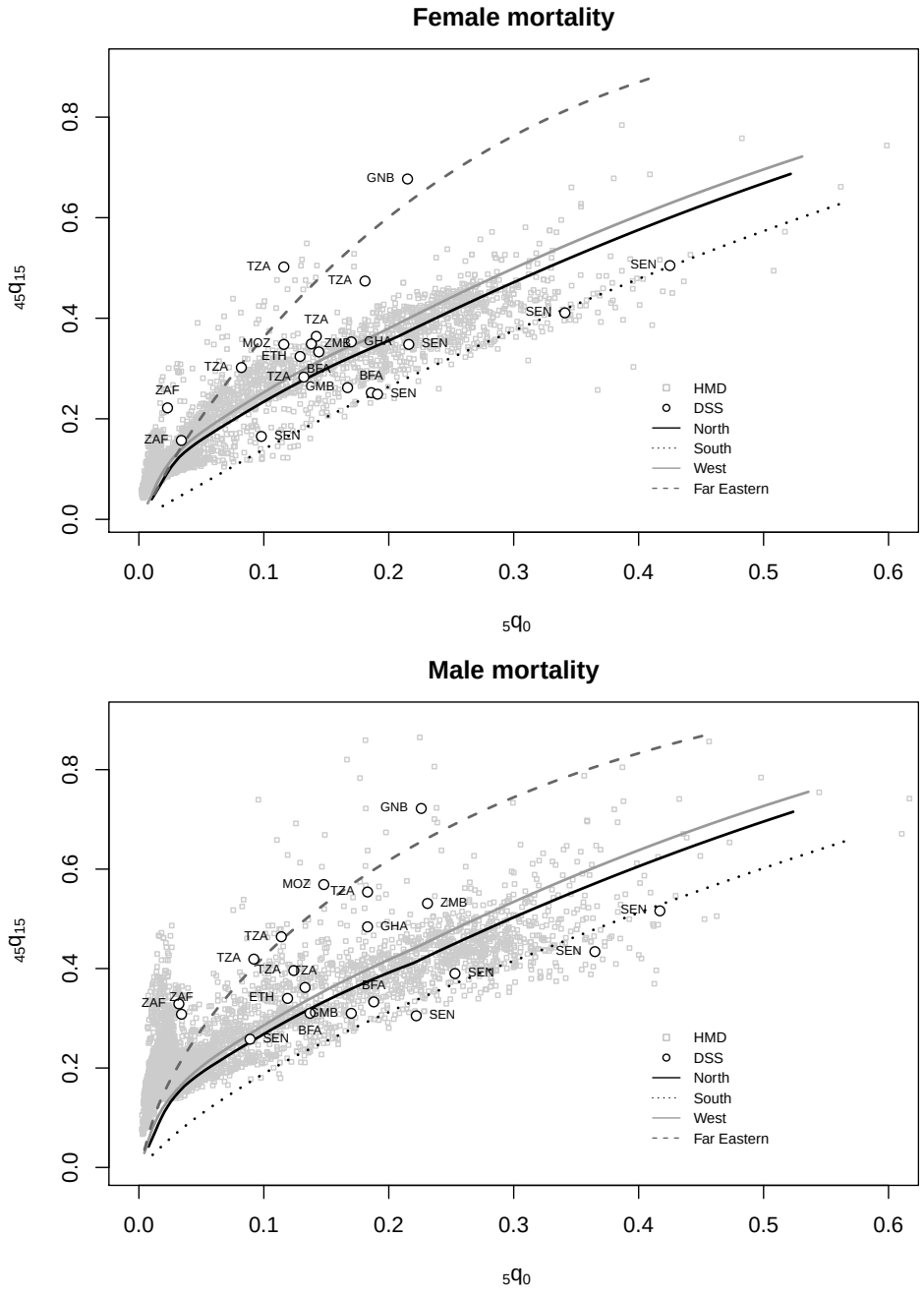
Var	Coef	exp(Coef)	Std.Error	p.value	sign
(Intercept)	0.430	1.538	0.053	0.000	***
15-Females	-0.106	0.900	0.017	0.000	***
15-Males	-0.112	0.894	0.018	0.000	***
20-Females	-0.078	0.925	0.017	0.000	***
20-Males	-0.008	0.992	0.018	0.663	
25-Males	-0.011	0.989	0.018	0.543	
30-Females	-0.041	0.960	0.017	0.014	*
30-Males	-0.165	0.848	0.018	0.000	***
35-Females	-0.030	0.971	0.017	0.077	.
35-Males	-0.217	0.805	0.018	0.000	***
40-Females	-0.108	0.898	0.017	0.000	***
40-Males	-0.334	0.716	0.018	0.000	***
45-Females	-0.111	0.895	0.017	0.000	***
45-Males	-0.337	0.714	0.018	0.000	***
50-Females	-0.137	0.872	0.017	0.000	***
50-Males	-0.427	0.653	0.018	0.000	***
55-Females	0.037	1.037	0.017	0.030	*
55-Males	-0.322	0.725	0.018	0.000	***
HIV	-0.011	0.989	0.002	0.000	***
E0	-0.035	0.966	0.014	0.012	*
Logit	-0.032	0.968	0.118	0.786	
South	-0.144	0.866	0.144	0.326	
West	0.350	1.419	0.128	0.011	*
Year	-0.005	0.995	0.001	0.000	***
15-Females:HIV	-0.038	0.963	0.002	0.000	***
15-Males:HIV	-0.020	0.980	0.003	0.000	***
20-Females:HIV	-0.012	0.988	0.002	0.000	***
20-Males:HIV	-0.010	0.990	0.003	0.000	***
25-Males:HIV	-0.003	0.997	0.003	0.185	
30-Females:HIV	0.009	1.009	0.002	0.000	***
30-Males:HIV	-0.002	0.998	0.003	0.520	
35-Females:HIV	0.005	1.005	0.002	0.022	*
35-Males:HIV	0.006	1.006	0.003	0.015	*
40-Females:HIV	-0.009	0.991	0.002	0.000	***
40-Males:HIV	-0.001	0.999	0.003	0.760	
45-Females:HIV	-0.032	0.969	0.002	0.000	***
45-Males:HIV	-0.011	0.989	0.003	0.000	***
50-Females:HIV	-0.052	0.950	0.002	0.000	***
50-Males:HIV	-0.029	0.971	0.003	0.000	***
55-Females:HIV	-0.051	0.951	0.002	0.000	***
55-Males:HIV	-0.036	0.964	0.003	0.000	***
HIV:E0	0.011	1.011	0.001	0.000	***

15-Females:Logit	-0.078	0.925	0.035	0.027	*
15-Males:Logit	-0.073	0.929	0.035	0.039	*
20-Females:Logit	0.076	1.079	0.035	0.032	*
20-Males:Logit	0.048	1.049	0.035	0.174	
25-Males:Logit	0.047	1.049	0.035	0.181	
30-Females:Logit	-0.092	0.912	0.035	0.009	**
30-Males:Logit	-0.058	0.944	0.035	0.103	
35-Females:Logit	-0.030	0.971	0.035	0.398	
35-Males:Logit	0.040	1.041	0.035	0.256	
40-Females:Logit	0.029	1.030	0.035	0.405	
40-Males:Logit	0.095	1.100	0.035	0.007	**
45-Females:Logit	0.156	1.169	0.035	0.000	***
45-Males:Logit	0.228	1.256	0.035	0.000	***
50-Females:Logit	0.108	1.114	0.035	0.002	**
50-Males:Logit	0.259	1.296	0.035	0.000	***
55-Females:Logit	0.154	1.166	0.035	0.000	***
55-Males:Logit	0.355	1.426	0.035	0.000	***
15-Females:South	-0.199	0.820	0.040	0.000	***
15-Males:South	-0.230	0.794	0.041	0.000	***
20-Females:South	0.010	1.010	0.040	0.806	
20-Males:South	-0.006	0.994	0.041	0.891	
25-Males:South	-0.001	0.999	0.041	0.972	
30-Females:South	-0.004	0.996	0.040	0.919	
30-Males:South	0.073	1.076	0.041	0.075	.
35-Females:South	-0.019	0.981	0.040	0.636	
35-Males:South	0.058	1.060	0.041	0.157	
40-Females:South	0.011	1.011	0.040	0.784	
40-Males:South	0.109	1.115	0.041	0.008	**
45-Females:South	0.025	1.025	0.040	0.533	
45-Males:South	0.123	1.131	0.041	0.003	**
50-Females:South	0.075	1.078	0.040	0.060	.
50-Males:South	0.191	1.210	0.041	0.000	***
55-Females:South	0.044	1.045	0.040	0.269	
55-Males:South	0.162	1.176	0.041	0.000	***
15-Females:West	-0.089	0.915	0.040	0.026	*
15-Males:West	-0.586	0.557	0.040	0.000	***
20-Females:West	-0.024	0.976	0.040	0.547	
20-Males:West	-0.604	0.547	0.040	0.000	***
25-Males:West	-0.459	0.632	0.040	0.000	***
30-Females:West	-0.028	0.973	0.040	0.488	
30-Males:West	-0.359	0.698	0.040	0.000	***
35-Females:West	-0.121	0.886	0.040	0.002	**
35-Males:West	-0.335	0.716	0.040	0.000	***

40-Females:West	-0.121	0.886	0.040	0.002	**
40-Males:West	-0.293	0.746	0.040	0.000	***
45-Females:West	-0.067	0.935	0.040	0.091	.
45-Males:West	-0.278	0.757	0.040	0.000	***
50-Females:West	0.057	1.059	0.040	0.153	
50-Males:West	-0.145	0.865	0.040	0.000	***
55-Females:West	0.085	1.089	0.040	0.032	*
55-Males:West	-0.074	0.929	0.040	0.068	.
E0:Logit	0.010	1.010	0.015	0.502	
E0:South	0.029	1.029	0.029	0.324	
E0:West	-0.115	0.891	0.017	0.000	***
15-Females:E0	-0.002	0.998	0.015	0.885	
15-Males:E0	-0.005	0.995	0.015	0.713	
20-Females:E0	0.012	1.012	0.015	0.407	
20-Males:E0	-0.008	0.992	0.015	0.584	
25-Males:E0	-0.026	0.975	0.015	0.084	.
30-Females:E0	-0.039	0.961	0.015	0.007	**
30-Males:E0	-0.054	0.948	0.015	0.000	***
35-Females:E0	-0.071	0.931	0.015	0.000	***
35-Males:E0	-0.097	0.907	0.015	0.000	***
40-Females:E0	-0.095	0.909	0.015	0.000	***
40-Males:E0	-0.149	0.862	0.015	0.000	***
45-Females:E0	-0.114	0.892	0.015	0.000	***
45-Males:E0	-0.187	0.829	0.015	0.000	***
50-Females:E0	-0.139	0.870	0.015	0.000	***
50-Males:E0	-0.229	0.795	0.015	0.000	***
55-Females:E0	-0.172	0.842	0.015	0.000	***
55-Males:E0	-0.264	0.768	0.015	0.000	***
HIV:Logit	0.043	1.044	0.008	0.000	***
HIV:South	0.017	1.017	0.004	0.000	***
HIV:West	-0.003	0.997	0.001	0.024	*

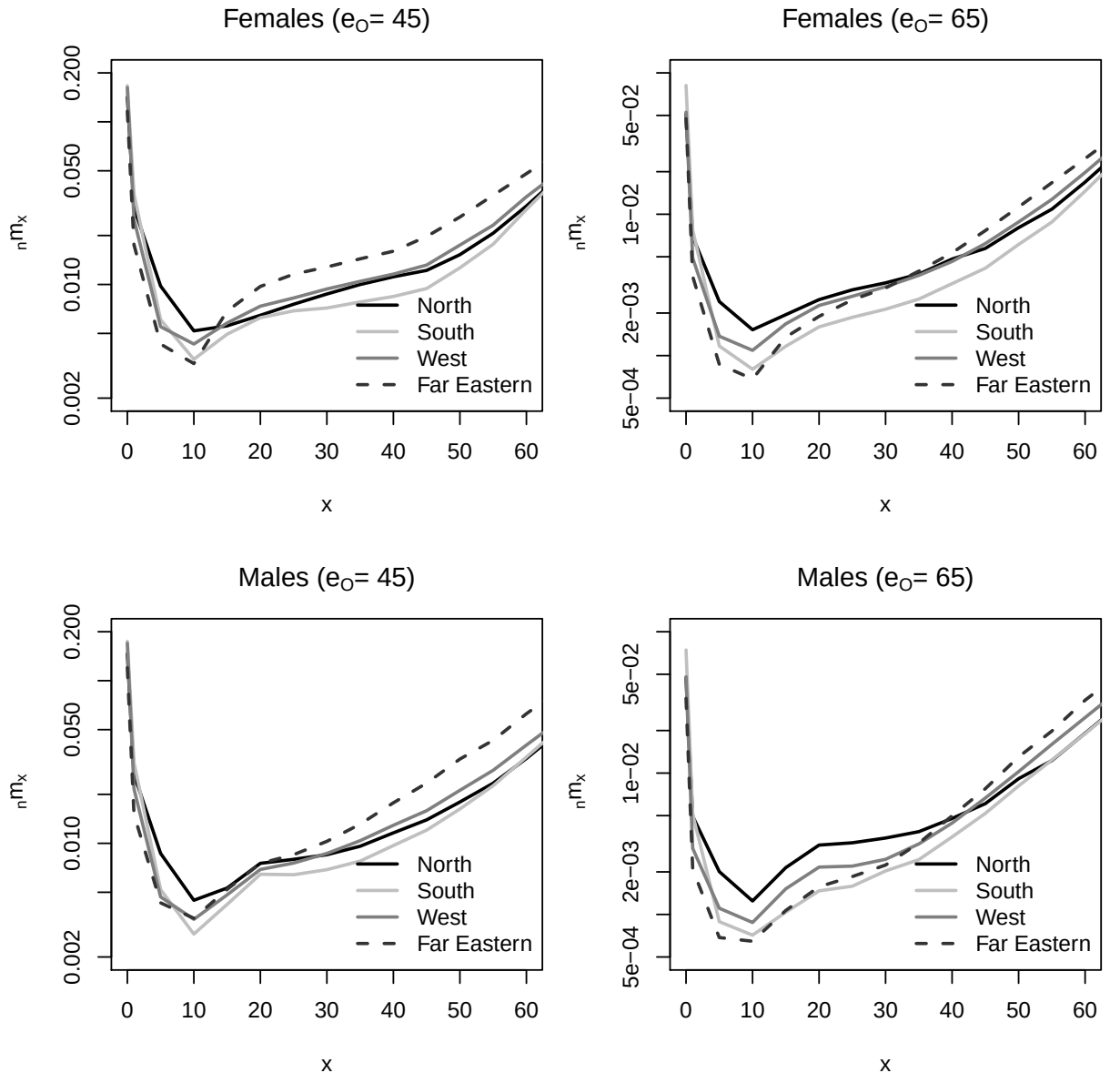
Table 5 – *Fixed-effects parameter estimates for the regression of the logged ratios of UNPD to sibling probabilities* ${}_5q_n$

Figure 1 – *Relationship between levels of child and adult mortality in demographic surveillance sites (dots), in the Human Mortality Database (squares) and in 4 model schedules of mortality (lines)*



Source: Model lifes tables (adapted from Coale et al. (1983) and United Nations (1982)) were downloaded from the UN Population Estimates and Projections Section website (http://esa.un.org/wpp/Model-Life-Tables/download-page.html). Estimates for demographic surveillance sites are published in INDEPTH (2004). Additional estimates for Senegal and South Africa are taken from Pison and Langaney (1985), Pison and Desgrées du Loû (1993) and Cook et al. (2008). The HMD data is distributed by the University of California, Berkeley (USA), and the Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org (data downloaded on June 2009).

Figure 2 – *Death rates implied by different model age patterns for life expectancies at birth of 45 and 65 years*



Source: Model lifes tables (adapted from Coale et al. (1983) and United Nations (1982)) were downloaded from the UN Population Estimates and Projections Section website (http://esa.un.org/wpp/Model-Life-Tables/download-page.html).

Figure 3 – *Estimated rate ratios associated with the number of completed years prior to the survey, estimated by pooling together all overlapping periods in 40 DHS conducted in 17 sub-Saharan countries*

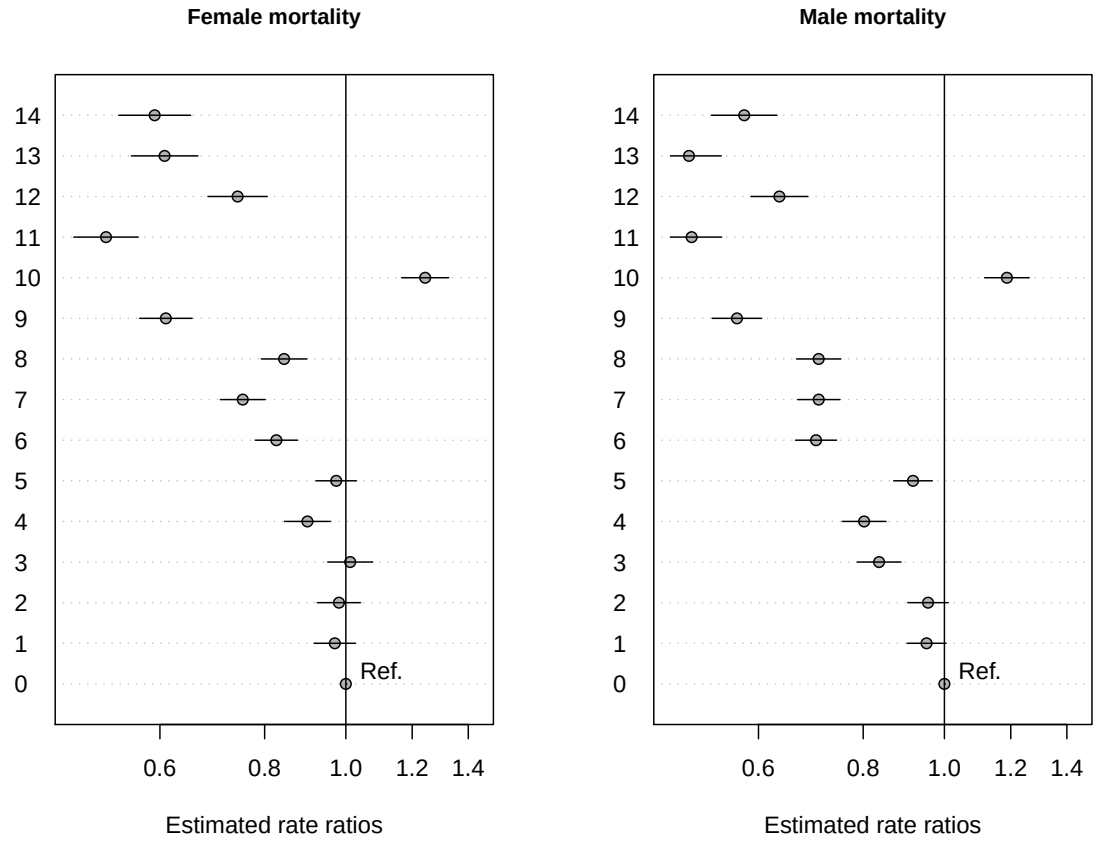
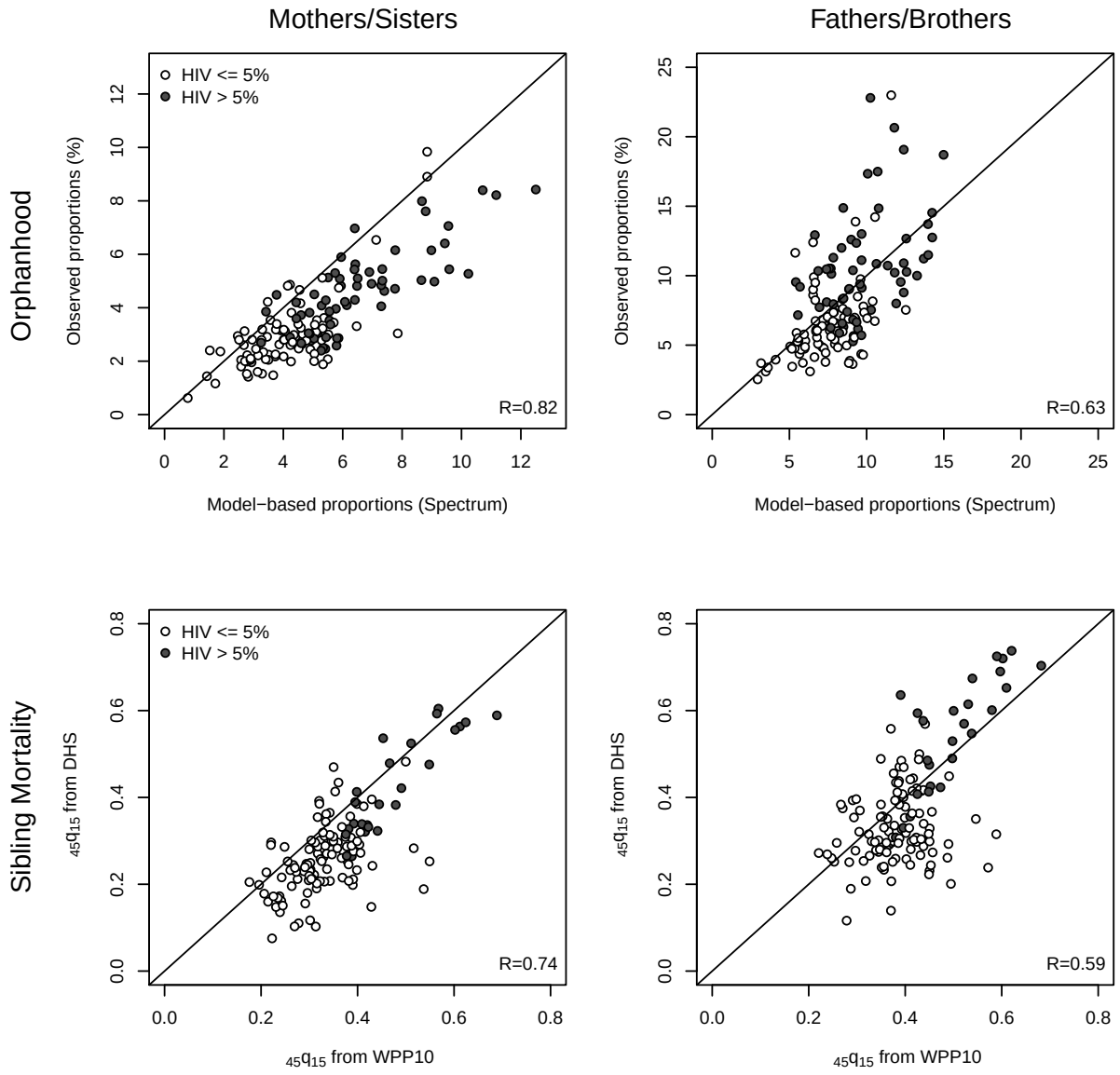


Figure 4 –
Upper panel: Comparison between prevalence of orphanhood among 5- to 9-year olds observed in surveys and census (y-axis) and Spectrum estimates (x-axis)
Lower panel: Comparison between values of ${}_{45}q_{15}$ estimated from sibling histories (y-axis) compared with UNPD estimates (x-axis)



Note: In the upper panel, comparisons are made for each available point estimate of orphan prevalence, with years ranging from 1976 to 2010. Estimates for Burkina Faso, Gambia, Mali, Mauritania, Niger, Senegal, Sierra Leone, Mauritius and Reunion are not presented because the background mortality used in Spectrum differs from the one estimated by the UNPD. In the lower panel, sibling estimates are compared with UNPD estimates for the years 1983, 1988, 1993, 1998, 2003 and 2008.

Figure 5 – *Ratios between Spectrum estimates and proportions of children aged 10 to 14 who are orphaned observed in surveys and censuses, by sex of parent, observed orphan prevalence, level of HIV prevalence 5 years prior to the survey or census, and non-AIDS life expectancy estimated by the UNPD (1976-2010)*

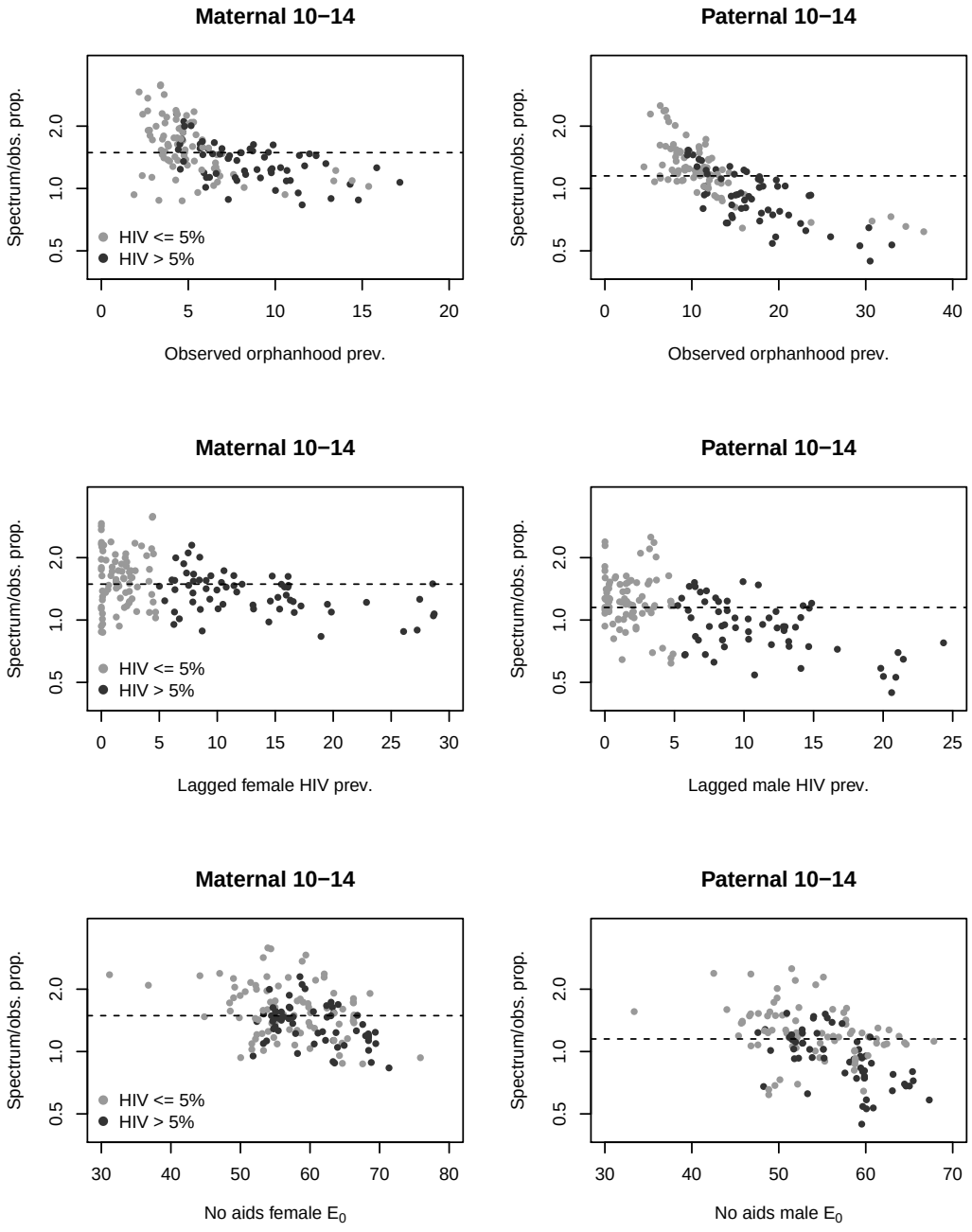


Figure 6 – *Ratios between probabilities of dying in adulthood produced for the WPP 2010 and estimates derived from sibling histories, by sex, age group and level of lagged HIV prevalence (1981-2010)*

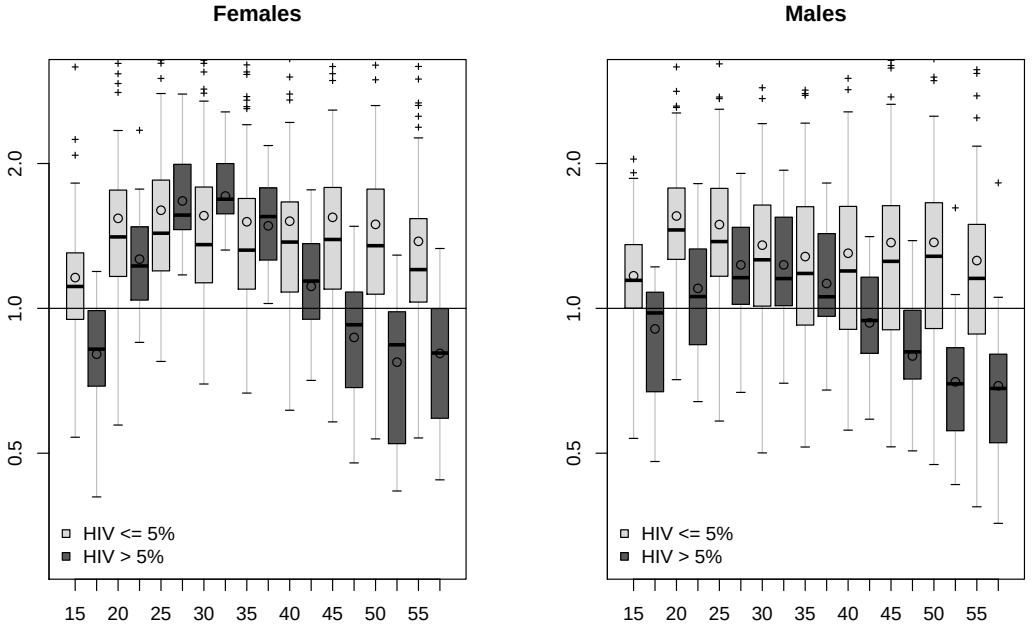


Figure 7 – *Probabilities of dying in adulthood produced for the WPP 2010 (for 1998) and estimates derived from sibling histories (for 1998), compared with estimates from civil registration data and the 1997 Population survey of Zimbabwe (Feeney 2001) and Demographic surveillances sites in Tanzania (INDEPTH 2002)*

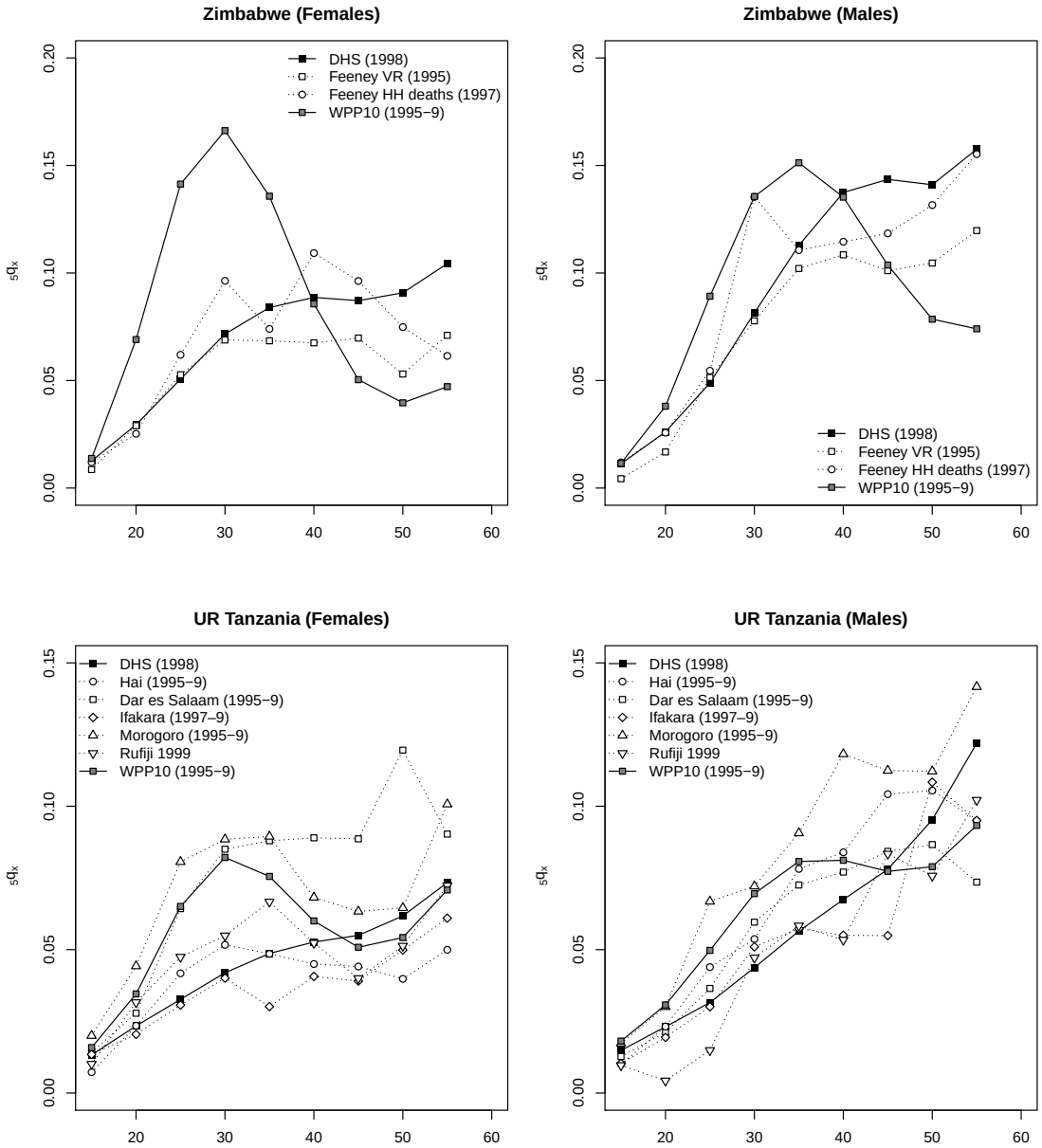


Figure 8 – *Predicted ratios of modelled to observed proportions of orphans (using only fixed effects) according to HIV prevalence, life expectancy at birth in the no-AIDS scenario and model schedules of background mortality.*

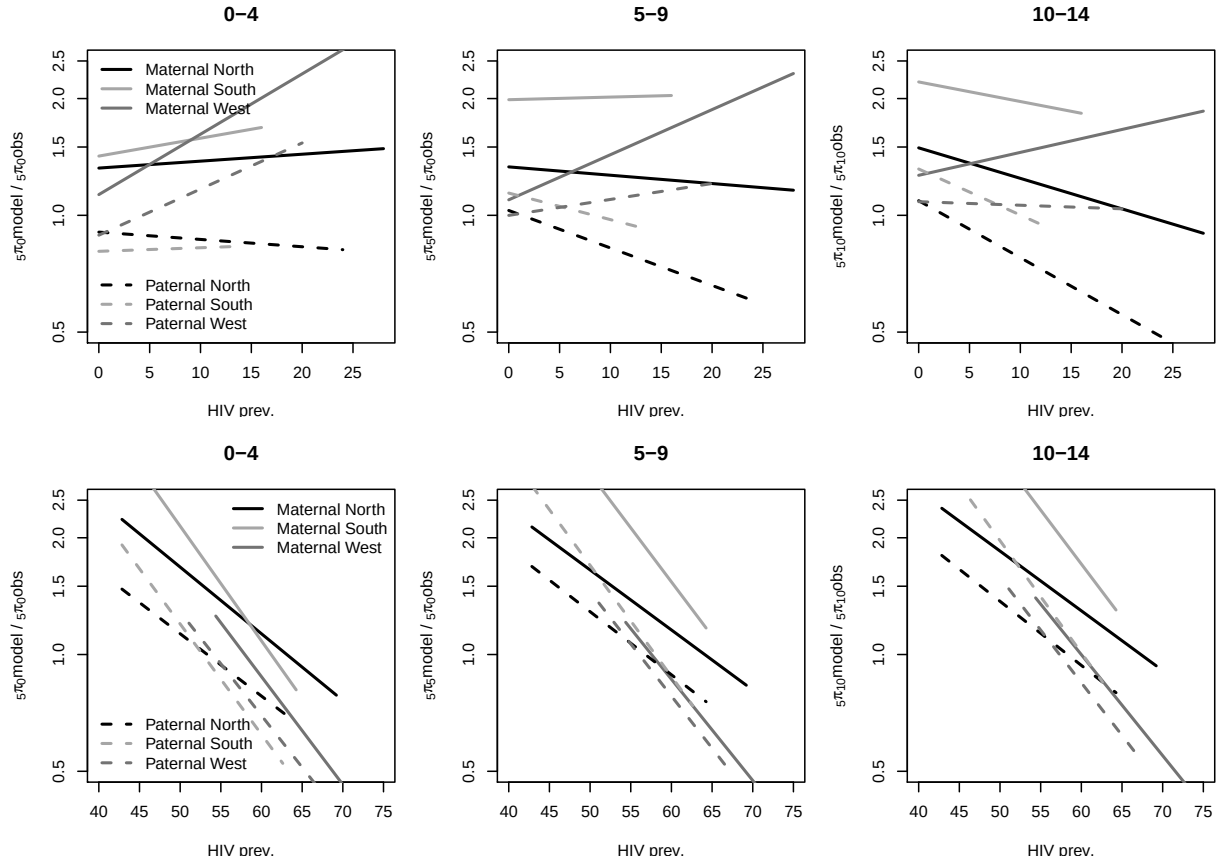


Figure 9 – *Predicted ratios of modelled to observed probabilities ${}_5q_x$ (using only fixed effects) according to HIV prevalence, life expectancy at birth in the no-AIDS scenario and model schedules of background mortality.*

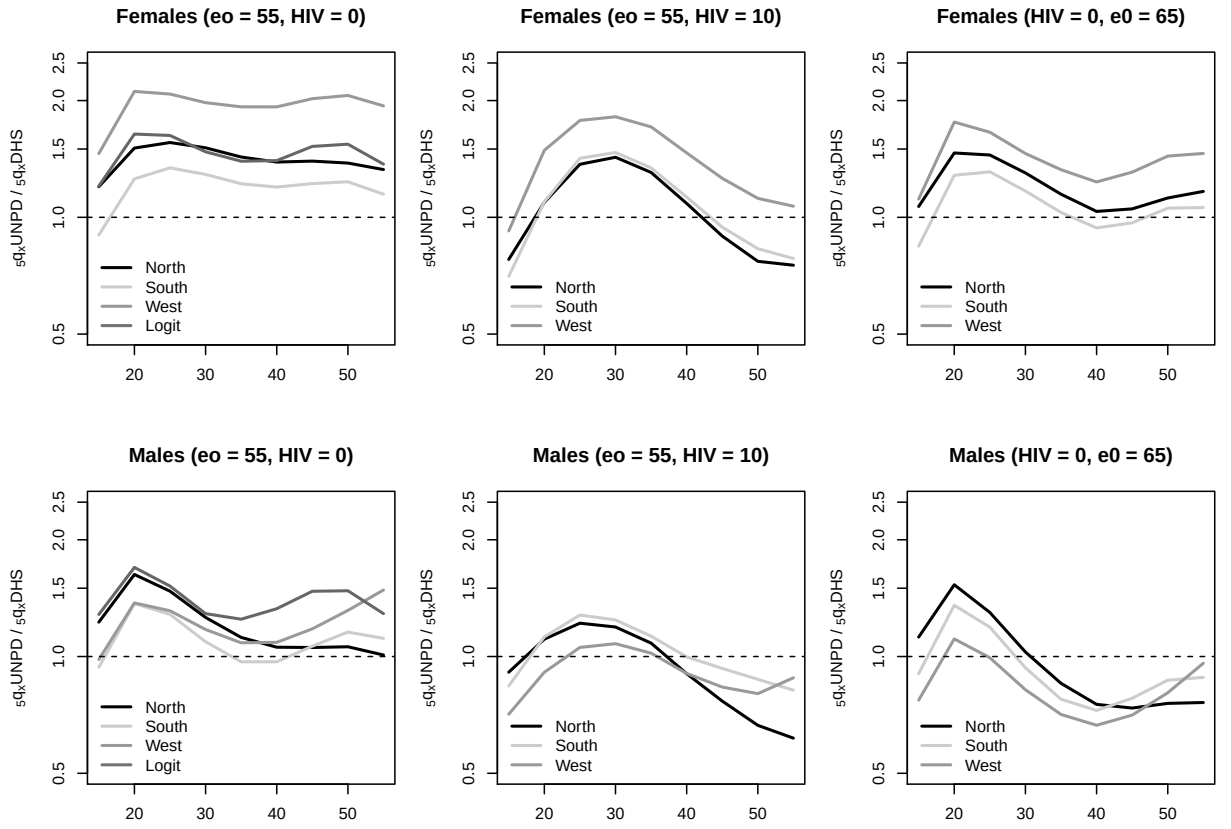
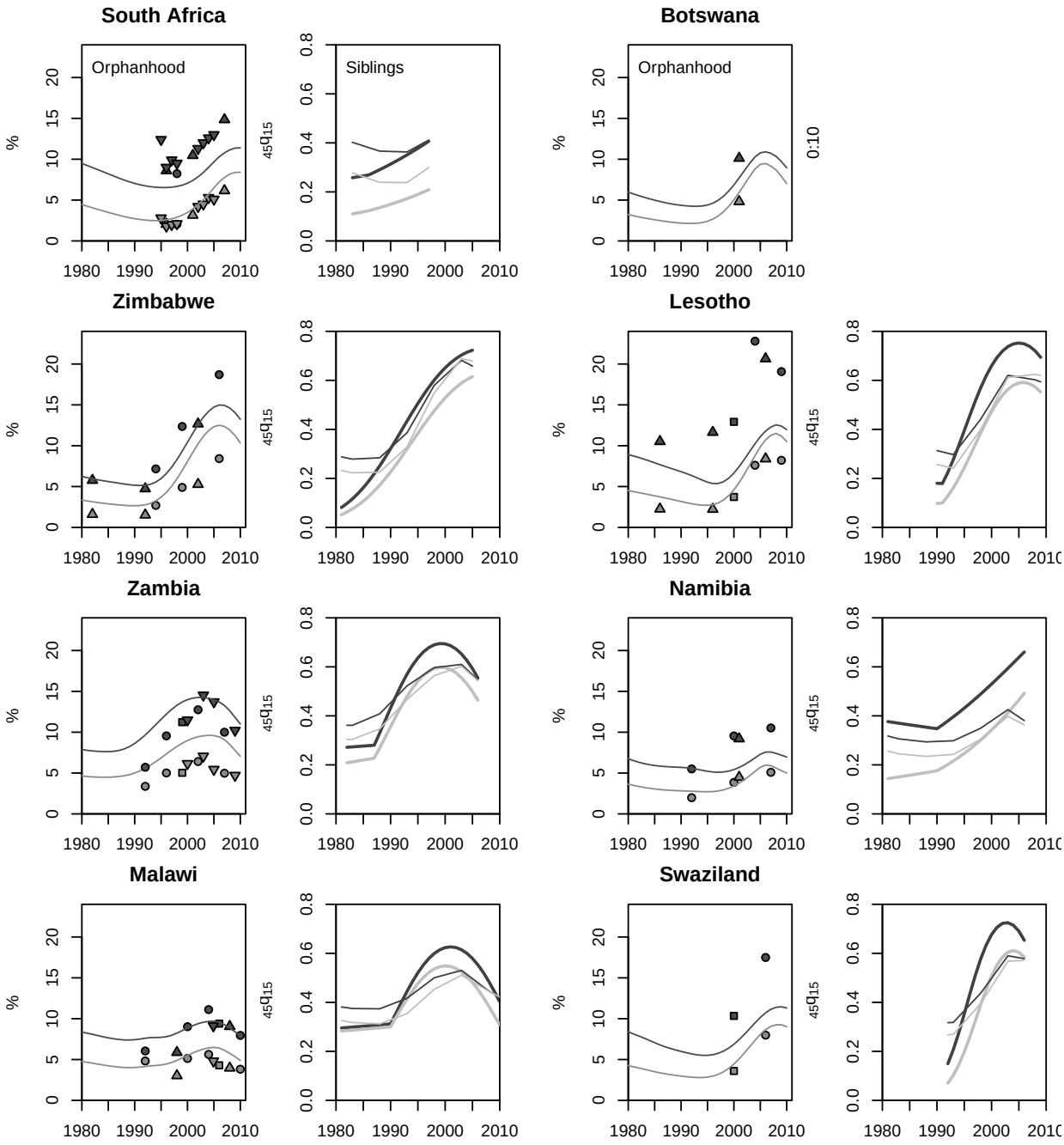
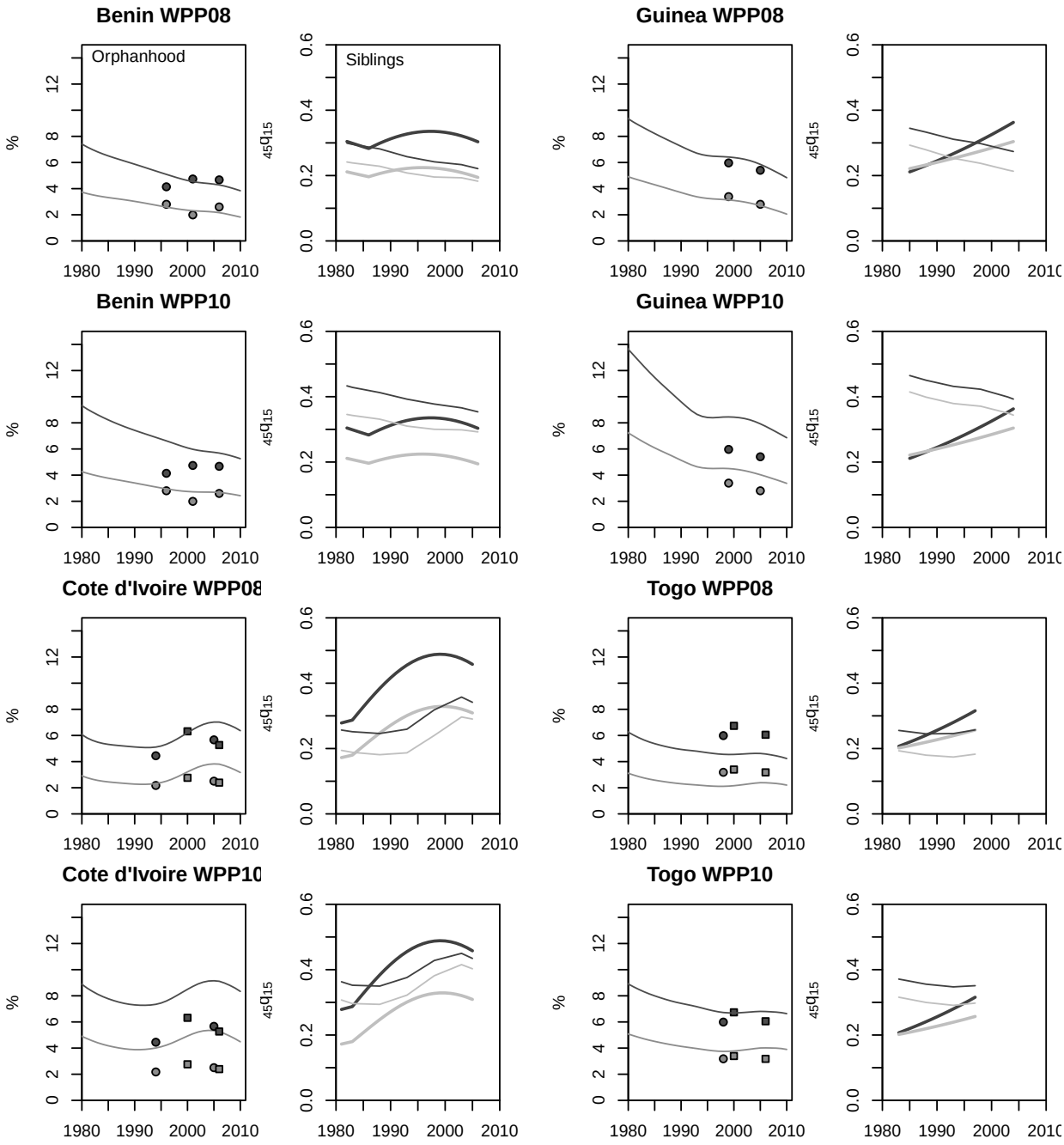


Figure 10 – *Left panels: Prevalence of orphanhood among 5- to 9-year olds (paternal orphans in dark) observed in surveys and census (dots) versus Spectrum estimates (lines)*
Right panels: Trends in ${}_{45}q_{15}$ by sex (males in dark) estimated from sibling histories (bold) compared with UNPD estimates (lines)



Note: in the orphanhood plots, symbols are attributed as follows: upside down triangles for census estimates, circles for DHS estimates, squares for MICS estimates and triangles for other surveys.

Figure 11 – *Left panels: Prevalence of orphanhood among 5- to 9-year olds (paternal orphans in dark) observed in surveys and census (dots) versus Spectrum estimates (lines)*
Right panels: Trends in ${}_{45}q_{15}$ by sex (males in dark) estimated from sibling histories (bold) compared with UNPD estimates (lines)



Note: in the orphanhood plots, symbols are attributed as follows: upside down triangles for census estimates, circles for DHS estimates, squares for MICS estimates and triangles for other surveys.

References

M. Adjuik, T. Smith, S. Clark, J. Todd, A. Garrib, Y. Kinfu, K. Kahn, M. Mola, A. Ashraf, and H. et al. Masanja. Cause-specific mortality rates in sub-Saharan Africa and Bangladesh. *Bulletin of the World Health Organization*, 84(3):181–188, 2006.

F. Baryarama, R.a Bunnell, W. McFarland, E. Hudes, T. Neilands, R. Ransom, J. Mubangizi, C. Hitimana-Lukanika, and J. Mermin. Estimating HIV Incidence in Voluntary Counseling and Testing Clients in Uganda (1992-2003). *JAIDS Journal of Acquired Immune Deficiency Syndromes*, 44(1):99–105, 2007.

K. Beegle, D. Filmer, A. Stokes, and L. Tiererova. Orphanhood and the Living Arrangements of Children in Sub-Saharan Africa. *World Development*, 38(12):1727–1746, 2010.

N. Bennett and S. Horiuchi. Mortality estimation from registered deaths in less developed countries. *Demography*, 21(2):217–234, 1984.

J. Blacker. The Estimation of Adult Mortality in Africa from Data on Orphanhood. *Population Studies*, 31 (1):107–128, 1977.

J. Blacker. Experience in the use of special mortality questions in multipurpose surveys: the single-round approach. In United Nations, editor, *Data bases for mortality measurement*, chapter IX, pages 79–89. United Nations, New York, 1984.

J. Blacker and J. Mukiza-Gapere. The indirect measurement of adult mortality in Africa: results and prospects. In International Union for the Scientific Study of Population , editor, *African Population Conference, Dakar, Senegal, November 7-12, 1988*, pages 23–38. IUSSP, 1988.

D. Bradshaw and I. Timaeus. Levels and Trends of Adult Mortality. In D. Jamison, R. Feachem, M. Makgoba, E. Bos, F. Baingana, K. Hofman, and K. Rogo, editors, *Disease and Mortality in Sub-Saharan Africa*, chapter 4, pages 31–42. World Bank, 2006.

W. Brass and K. Hill. Estimating adult mortality from orphanhood. In International Union for the Scientific Study of Population, editor, *Proceedings of the International Population Conference: Liège*, volume 3, pages 111–123, 1973.

W. Brass, A. Coale, P. Demeny, D. Heisel, F. Lorimer, A. Romaniuk, and E. van de Walle. *The Demography of tropical Africa*. Princeton University Press, 1968.

T. Brown, N. Grassly, G. Garnett, and K. Stanecki. Improving projections at the country level: the UNAIDS Estimation and Projection Package 2005. *Sexually Transmitted Infections*, 82:iii34–iii40, 2006.

T. Brown, J. Salomon, L. Alkema, A. Raftery, and E. Gouws. Progress and challenges in modelling country-level HIV/AIDS epidemics: the UNAIDS Estimation and Projection Package 2007. *Sexually Transmitted Infections*, 84 (S1):i5–i–10, 2008.

T. Brown, L. Bao, A. Raftery, J. Salomon, R. Baggaley, J. Stover, and P. Gerland. Modelling HIV epidemics in the antiretroviral era: the UNAIDS Estimation and Projection package 2009. *Sexually Transmitted Infections*, 86(Suppl 2):ii3–ii10, 2010.

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

I. Cook, M. Alberts, S. Burger, and P. Byass. All-cause mortality trends in Dikgale, rural South Africa, 1996-2003. *Scandinavian Journal of Public Health*, 36(7):753–760, 2008.

R. Dorrington, D. Bourne, D. Bradshaw, R. Laubscher, and I. Timaeus. The impact of HIV/AIDS on adult mortality in South Africa. Technical Report, Burden of Disease Research Unit Medical Research Council, 2001.

I. Ekanem and R. Som. The problem of choosing model life tables for African countries. *Genus*, 40(1-2): 57–70, 1984.

G. Feeney. The impact of HIV/AIDS on adult mortality in Zimbabwe. *Population and Development Review*, 27, 4:771–780, 2001.

E. Gakidou and G. King. Death by survey: estimating adult mortality without selection bias from sibling survival data. *Demography*, 43 (3): 569–585, 2006.

E. Gakidou, M. Hogan, and A. Lopez. Adult mortality: time for a reappraisal. *International Journal of Epidemiology*, 33, 4:710–717, 2004.

E. Gouws, V. Mishra, and T. Fowler. Comparison of adult HIV prevalence from national population-based surveys and antenatal clinic surveillance in countries with generalised epidemics: implications for calibrating surveillance data. *Sexually Transmitted Infections*, 84 (S1):i17–i23, 2008.

N. Grassly and I. Timaeus. Methods to estimate the number of orphans as a result of AIDS and other causes in sub-Saharan Africa. *JAIDS Journal of Acquired Immune Deficiency Syndromes*, 39:635–75, 2005.

N. Grassly, J. Lewis, M. Mahy, N. Walker, and I. Timaeus. Comparison of household-survey estimates with projections of mortality and orphan numbers in sub-Saharan Africa in the era of HIV/AIDS. *Population Studies*, 58:2:207–217, 2004.

S. Gregson, G. Garnett, C. Nyamukapa, T. Hallett, J. Lewis, P. Mason, S. Chandiwana, and R. Anderson. HIV Decline Associated with Behavior Change in Eastern Zimbabwe. *Science*, 311(5761):664–666, 2006.

T. Hallett, B. Zaba, J. Todd, B. Lopman, W. Mwita, S. Biraro, S. Gregson, and J. Boerma. Estimating Incidence from Prevalence in Generalised HIV Epidemics: Methods and Validation. *PLoS Med*, 5(4):e80, 2008.

L. Henry. Mesure indirecte de la mortalité des adultes. *Population*, 15, 3: 457–466, 1960.

P. Heuveline. HIV and population dynamics: a general model and maximum-likelihood standards for East Africa. *Demography*, 40(2):217–245, 2003.

K. Hill. Estimating Census and Death Registration Completeness. *Asian and Pacific Population Forum*, 1(3): 8–13, 1987.

K. Hill and J. Trussell. Further developments in indirect mortality estimation. *Population Studies*, 31(2):313–334, 1977.

K. Hill, Y. Choi, and I. Timaeus. Unconventional approaches to mortality estimation. *Demographic research*, 13(12):281–300, 2005.

INDEPTH. *Population and health in developing countries, Population, health and survival at INDEPTH sites*, volume 1. International Development Research Centre, 2002.

INDEPTH. *INDEPTH model life tables for Sub-Saharan Africa*. Ashgate, 2004.

A. Kilian, S. Gregson, B. Ndyanabangi, K. Walusaga, W. Kipp, G. Sahlmüller, G. Garnett, G. Asiimwe-Okiror, G. Kabagambe, P. Weis, and F. Von Sonnenburg. Reductions in risk behaviour provide the most consistent explanation for declining HIV-1 prevalence in Uganda. *AIDS*, 13 (3):391–398, 1999.

B. Lopman, C. Nyamukapa, T. Hallett, P. Mushati, N. Spark-du Preez, F. Kurwa, M. Wambe, and S. Gregson. Role of widows in the heterosexual transmission of HIV in Manicaland, Zimbabwe, 1998-2003. *Sex Transm Infect*, 85 Suppl 1:i41–8–, 2009.

M Luy. A Classification of the Nature of Mortality Data Underlying the Estimates for the 2004 and 2006 United Nations World Population Prospects. *Comparative Population Studies*, 35 (2):315–334, 2010.

B. Masquelier. Adult Mortality from Sibling Survival Data: A Reappraisal of Selection Biases. *Demography*, forthcoming.

R. Monasch and J. Boerma. Orphanhood and childcare patterns in sub-Saharan Africa: an analysis of national surveys from 40 countries. *AIDS*, 18(2):55–65, 2004.

T. Mulder and P. Johnson. Analysis of demographic models used to incorporate HIV/AIDS-related mortality. Paper presented at the XXV International Population Conference, IUSSP, Tours, France, July 18-23, 2005.

Ch. Murray, B. Ferguson, A. Lopez, M. Guillot, J. Salomon, and O. Ahmad. Modified logit life table system: principles, empirical validation, and application. *Population Studies*, 57(2):165–182, 2003.

Z. Obermeyer, C. Murray, and E. Gakidou. Fifty years of violent war deaths from Vietnam to Bosnia: analysis of data from the world health survey programme. *BMJ*, 336:1482–1486, 2008.

Z. Obermeyer, J. Rajaratnam, C. Park, E. Gakidou, M. Hogan, A. Lopez, and Ch. Murray. Measuring Adult Mortality Using Sibling Survival: A New Analytical Method and New Results for 44 Countries, 1974-2006. *PLoS Medicine*, 7(4):e1000260, 04 2010.

W. Paget and I. Timaeus. A Relational Gompertz Model of Male Fertility: Development and Assessment. *Population Studies*, Vol. 48, No. 2.:333–340, 1994.

G. Pison and A. Desgrées du Loû. *Bandafassi (Sénégal): Niveaux et tendances démographiques 1971-1991*. Dossier et Recherches No. 40., 1993.

G. Pison and A. Langaney. The level and age pattern of mortality in bandafassi (eastern senegal): Results from a small-scale and intensive multi-round survey. *Population Studies*, 39(3):pp. 387–405, 1985.

G. Pison and A. Langaney. Age Patterns of Mortality in Eastern Senegal : Comparison of Micro and Survey Approaches. In V. Caldwell J., Hill A. et Hull, editor, *Micro-approaches to demographic research*, pages 297–317. Kegan Paul International, London, 1988.

S. Preston. *Mortality patterns in national populations: with special reference to recorded causes of death*. Studies in Population. Academic Press, 1976.

S. Preston and N. Bennett. A census-based method for estimating adult mortality. *Population Studies*, 37(1): 91–104, 1983.

Samuel H. Preston. An integrated system for demographic estimation from two age distributions. *Demography*, 20(2):pp. 213–226, 1983. ISSN 00703370. URL http://www.jstor.org/stable/2061236.

Th. Pullum. An Assessment of the Quality of Data on Health and Nutrition in the DHS Surveys, 1993-2003. DHS Methodological Reports No. 6., Calverton, Maryland: Macro International Inc., 2008.

J. Rajaratnam, J. Marcus, A. Levin-Rector, A. Chalupka, H. Wang, L. Dwyer, M. Costa, A. Lopez, and Ch. Murray. Worldwide mortality in men and women aged 15-59 years from 1970 to 2010: a systematic analysis. *The Lancet*, 375(9727):1704 – 1720, 2010.

S. Renata. Child fostering in Africa: When labor and schooling motives may coexist. *Journal of Development Economics*, 88(1):157 – 170, 2009.

G. Reniers and J. Eaton. Refusal bias in HIV prevalence estimates from nationally representative seroprevalence surveys. *AIDS*, 23(5):621–629, 2009.

G. Reniers, B. Masquelier, and P. Gerland. Adult Mortality in Africa. In R. Rogers and E. Crimmins, editors, *International Handbook of Adult Mortality*. Springer, 2011.

L. Robertson, S. Gregson, C. Madanhire, N. Walker, P. Mushati, G. Garnett, and C. Nyamukapa. Discrepancies between UN models and DHS survey estimates of maternal orphan prevalence: insights from analyses of survey data from Zimbabwe. *Sexually Transmitted Infections*, 84 S(1): 57–62, 2008.

O. Sankoh, P. Ngom, S. Clark, D. de Savigny, , and F. Binka. Levels and Patterns of Mortality at INDEPTH Demographic Surveillance Systems. In D. Jamison, R. Feachem, M. Makgoba, E. Bos, F. Baingana, K. Hofman, and K. Rogo, editors, *Disease and Mortality in Sub-Saharan Africa*, chapter 7, pages 74–87. World Bank, 2006.

L. Shafer, S. Biraro, J. Nakiyingi-Miiro, A. Kamali, D. Ssematimba, J. Ouma, A. Ojwiya, P. Hughes, L. Van der Paal, J. Whitworth, A. Opio, and H. Grosskurth. HIV prevalence and incidence are no longer falling in southwest Uganda: evidence from a rural population cohort 1989-2005. *AIDS*, 22(13):1641–1649, 2008.

D. Sharrow and S. Clark. A parametric investigation of mortality at all ages in a rural, south african population, paper presented at the 2010 annual meeting of the population association of america. 2010.

C. Stanton, A. Noureddine, and K. Hill. DHS Maternal Mortality Indicators: an assessment of data quality and implications for Data Use. *Studies in Family planning*, 31,2:111–123, 2000.

J. Stover, P. Johnson, B. Zaba, M. Zwahlen, F. Dabis, and R. Ekpini. The Spectrum projection package: improvements in estimating mortality, ART needs, PMTCT impact and uncertainty bounds. *Sexually Transmitted Infections*, 84(Suppl 1):i24–i30, August 2008.

J. Stover, P. Johnson, T. Hallett, M. Marston, R. Becquet, and I. Timaeus. The Spectrum projection package: improvements in estimating incidence by age and sex, mother-to-child transmission, HIV progression in children and double orphans. *Sexually Transmitted Infections*, 86(Suppl 2):ii16–ii21, 2010. doi: 10.1136/sti.2010.044222. URL http://sti.bmj.com/content/86/Suppl_2/ii16.abstract.

D. Swanson, J. Tayman, and T. Bryan. MAPE-R: a rescaled measure of accuracy for cross-sectional subnational population forecasts. *Journal of Population Research*, 28:225–243, 2011. ISSN 1443-2447.

I. Timaeus. An Assessment of Methods for Estimating Adult Mortality from Two Sets of Data on Maternal Orphanhood. *Demography*, 23, 3:435–450, 1986.

I. Timaeus. Estimation of Mortality from Orphanhood in Adulthood. *Demography*, 28 (2):213–227, 1991a.

I. Timaeus. Measurement of adult mortality in less developed countries: A comparative review. *Population Index*, 57(4):pp. 552–568, 1991b. ISSN 00324701. URL http://www.jstor.org/stable/3644262.

I. Timaeus. Estimation of Adult Mortality from Orphanhood Before and Since Marriage. *Population Studies*, 45(3):455–472, 1991c.

I. Timaeus. New estimates of adult mortality from DHS data on the timing of orphanhood relative to marriage. Proceedings of the Demographic and Health Surveys World Conference, Washington D.C., 1991d. Vol. II. Columbia, Md.: Institute for Resource Development/Macro International, Inc.

I. Timaeus. Estimation of adult mortality from paternal orphanhood: a reassessment and a new approach. *Population Bulletin of the United Nations*, 33:47–63, 1992.

I. Timaeus. Adult mortality. In K. Foote, K. Hill, and L. Martin, editors, *Demographic change in Sub-Saharan Africa*, chapter 6. Panel on the Population Dynamics of Sub-Saharan Africa, Committee on Population, Commission on Behavioral and Social Sciences and Education, National Research Council, 1993.

I. Timaeus. Age Patterns of Mortality in sub-Saharan Africa: An initial study of the impact of AIDS. Unpublished paper presented at the Population Association of America annual meeting, Washington, D.C., 27-29 March 1997., 1997.

I. Timaeus. "notes on a series of life table estimates of mortality in the countries of the sub-saharan africa region". unpublished manuscript prepared for who. 1999.

I. Timaeus and M. Jasseh. Adult mortality in Sub-Saharan Africa: evidence from demographic and health survey. *Demography*, 41, 4:757–772, 2004.

I. Timaeus and A. Nunn. Measurement of adult mortality in populations affected by AIDS: an assessment of the orphanhood method. *Health transition Review*, 7(2):23–43, 1997.

I. Timaeus, B. Zaba, and M. Ali. Estimation of adult mortality from data on adult siblings. In B. Zaba and J. Blacker, editors, *Brass tacks: essays in medical demography*, pages 43–66. Athlone Press, Londres, 2001.

J. Todd, J. Glynn, M. Marston, T. Lutalo, S. Biraro, W. Mwita, V. Suriyanon, R. Rangsin, K. Nelson, P. Sonnenberg, D. Fitzgerald, E. Karita, and B. Zaba. Time from HIV seroconversion to death: a collaborative analysis of eight studies in six low and middle-income countries before highly active antiretroviral therapy. *AIDS*, 21:S55–63, 2007.

J. Trussell and G. Rodriguez. A note on the sisterhood estimator of maternal mortality. *Studies in Family Planning*, 21 (6):344–346, 1990.

USAID UNAIDS, UNICEF. *Children on the Brink 2002 : A Joint Report on Orphan Estimates and Program Strategies*. UNAIDS, UNICEF, USAID, Washington DC, 2002.

UNICEF. *Africa's Orphaned and Vulnerable Generations: Children Affected by AIDS*. UNICEF, UNAIDS and PEPFAR, 2006.

United Nations. *Model Life Tables for Developing Countries*. New York: United Nations, 1982.

United Nations. World Population Prospects: The 2000 Revision. CD-ROM Edition - Extended Dataset in Excel and ASCII formats. (United Nations publication, POP/DB/WPP/Rev.2000), 2001.

United Nations. World Population Prospects: The 2002 Revision. CD-ROM Edition - Extended Dataset in Excel and ASCII formats. (United Nations publication, POP/DB/WPP/Rev.2002), 2003.

United Nations. World Population Prospects: The 2004 Revision. CD-ROM Edition - Extended Dataset in Excel and ASCII formats. (United Nations publication, POP/DB/WPP/Rev.2004), 2005a.

United Nations. *World Population Prospects: The 2004 Revision*, volume III: Analytical Report. Population Division, Dept. of International Economic and Social Affairs, United Nations, New York, 2005b.

United Nations. World Population Prospects: The 2006 Revision. CD-ROM Edition - Extended Dataset in Excel and ASCII formats. (United Nations publication, POP/DB/WPP/Rev.2006), 2007.

United Nations. World Population Prospects: The 2008 Revision. CD-ROM Edition - Extended Dataset in Excel and ASCII formats. (United Nations publication, ST/ESA/SER.A/283), 2009a.

United Nations. *World Population Prospects: The 2008 Revision*. Population Division, Dept. of International Economic and Social Affairs, United Nations, New York, 2009b.

B. Zaba, J. Whitworth, M. Marston, J. Nakiyingi, A. Ruberantwari, M. Urassa, R.i Issingo, G. Mwaluko, S. Floyd, A. Nyondo, and A. Crampin. HIV and Mortality of Mothers and Children: Evidence From Cohort Studies in Uganda, Tanzania, and Malawi. *Epidemiology*, 16(3):–, 2005.

B. Zaba, J. Todd, and S. et al. Biraro. Diverse age patterns of hiv incidence rates in africa. abstract tuac0201, xvii international aids conference, mexico, august 2008. 2008.