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Revisiting indirect methods based on orphanhood data with micro-simulations

Bruno Masquelier - masquelier@demo.ucl.ac.be
Centre de recherche en démographie et sociétés – Louvain University, Belgium

1- Background

It is well acknowledged that adult mortality in sub-Saharan Africa suffers from lack of scientific and political interest. This is partly due to the shortage of available empirical data, which limits the scope for direct estimation of adult death rates. Vital registration systems still cover a small fraction of deaths in most parts of the region (often less than 25%), with the exception of South Africa and Zimbabwe (Dorrington et al., 2001, Feeney, 2001). Therefore, for a large majority of countries, current estimates produced by international organizations like the UN Population Division and the WHO are obtained with a two-step procedure; the analyst first derives background mortality from a combination of child survival and model life tables[1], and then factors the demographic impact of AIDS into the estimates to rescale the age-specific mortality rates upward (United Nations, 2009). Alternatives estimates of adult mortality, such as those based on the survivorship of kins (mainly parents and siblings) reported by censuses and surveys respondents, are generally lower than the model outputs. They are often viewed as much less reliable, although orphanhood data and sibling histories seem to provide consistent estimates (Timaeus and Jasseh, 2004).

In this context of scarcity of vital data, the accuracy of model-based estimates has to be established through external comparisons with all available sources ; deaths recorded in households, growth balance method, extinct generation methods, survival of relatives of the respondent…. Among other sources, kin survivorship statistics are routinely used to check the plausibility of projection results. They may even provide lower bounds when the background mortality incorporated in models needs to be revised to reconcile the model outputs with empirical evidence (United Nations, 2005). For that reason, it is crucial to assess the strengths and weaknesses of the data used, as well as the degree of accuracy provided by the indirect methods based on orphanhood or sibling histories. In this paper, we focus on this second aspect. We first confront estimates derived from orphan prevalence observed in DHS with UNPD levels of prime-age adult mortality. Important discrepancies between those two sources are highlighted. This has echoes of similar and well established discrepancies between model-estimates and

[1] Mainly Princeton life tables in the case of UNPD, and modified logit system in the case of the WHO.

household survey estimates of *orphan prevalence*. But besides survey underdeclaration, violations of assumptions underlying the orphanhood method could also be at issue. In this paper, we apply conventional indirect methods to micro-simulation outputs, in order to assess the size of different biases. Especially, we discuss the problems related to the estimation of reference periods which arise in countries experiencing severe HIV-Aids epidemic and mortality reversals.

2- Discrepancies between model-based estimates & household-survey estimates of orphan prevalence and adult mortality

The empirical values of orphan prevalence serve as a basis for indirect techniques used to derive adult mortality estimates (Blacker and Mukiza Gapere, 1988; Feeney, 2001; Timaeus and Jasseh, 2004). Ideally, they should be consistent with UNAIDS/UNICEF estimates of maternal and paternal orphanhood, which are based on mathematical models relying on UNPD population projections.[2] But Grassly et al. (2004) have pointed out important discrepancies between those model-based estimates and the DHS/MICS empirical values. They showed that model predictions of maternal orphans are significantly higher than orphan prevalence observed in the surveys, irrespective of the level of national HIV prevalence. Interestingly, paternal orphan prevalence is more in agreement with model outputs. Grassly et al. (2004) have suggested that this is due to a combination of (1) over-estimation of adult mortality by UNPD life tables and (2) misreports of foster parents as biological parents. As regards the first point, it is worth noting that some authors recently suggested that UNPD estimates have consistently over-estimated background mortality in the last decade (Bradshaw and Timaeus, 2003). But since this hypothesis has been put forward on the basis of observation of mortality levels derived from kin survivorship, the eventuality of survey under-estimation cannot be ruled out. Data quality issues regarding sibling histories have been discussed elsewhere (Stanton et al., 2000). As for reports of orphans, the declaration error commonly referred to as the "adoption effect" seems to play a major role. This has been documented by Robertson et al. (2008) with data from the Manicaland Demographic Surveillance Site (Zimbabwe). The authors have analyzed the

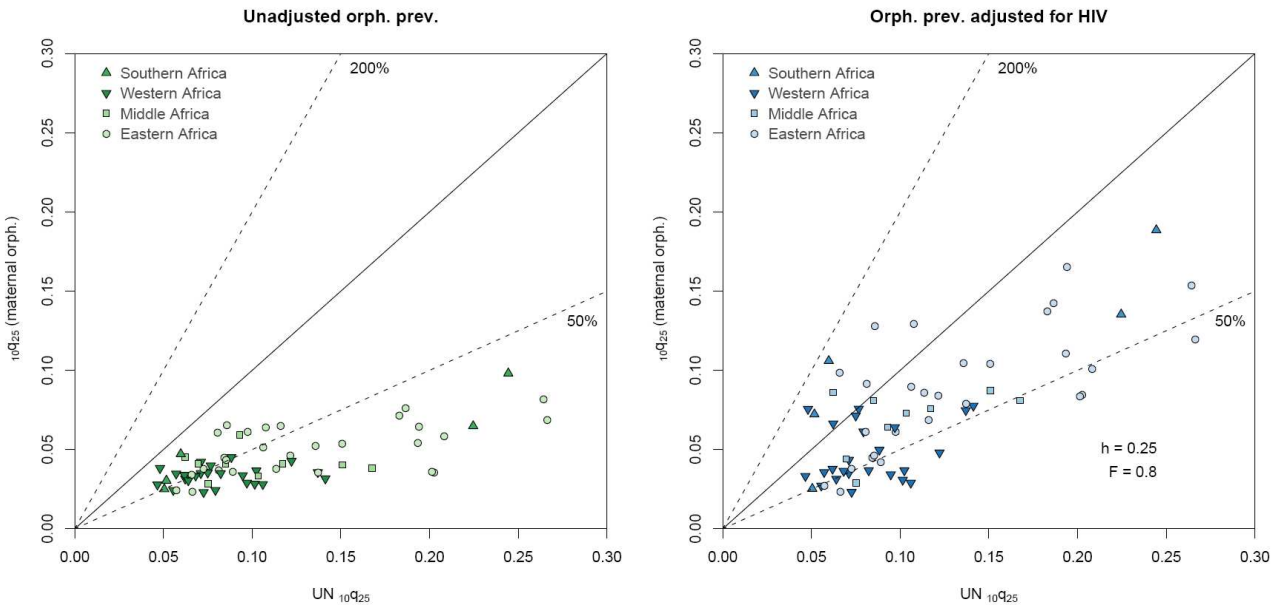
[2] A method used to derive estimates of the fraction of orphans as a result of AIDS and other causes is described in Grassly and Timaeus (2005).

consistency of reports of parent survival status across successive rounds and confirmed that a significant proportion of foster parents claim adopted orphans as their own children, thereby biasing orphan prevalence downwards. From internal comparisons of DHS data, Rutstein (2008) draws similar conclusions. Apart from this adoption effect, other data quality problems might be at stake, such as non-inclusion of institutionalized and homeless children in the DHS sample frame, selective migration of orphans, or age heaping on round ages. This heaping will tend to move some children upward in age, and cause a slight underestimation of mortality.

Downward biased estimates of orphan prevalence will mechanically result in underestimation of adult mortality, once converted into conditional probabilities of survivorship trough the orphanhood method. A brief summary of the parental survivorship method and its variants will be presented in the next section. Here, we transform DHS data on orphanhood into measures of adult mortality and show evidence of strong underestimation of mortality from maternal survivorship. Figure 1 confronts UNPD estimates of the female probability of death between age 25 and 35 ($_{10}q_{25}$) with estimates obtained from DHS maternal orphanhood. All DHS surveys for which data could be accessed on July, 1, 2009 are taken into account,[3] for children aged 5-9. Estimates of female mortality are obtained with coefficients taken from Timaeus (1992) and time reference period are calculated following the approach suggested by Brass and Bamgboye (1981) (first plot). In the second plot, estimates are adjusted for HIV-related selection biases described in the next section (Timaeus and Nuun, 1997)[4]. Moreover, for countries with HIV prevalence higher than 1% at the time of birth of children (approximately 7.5 years before the survey), the converting factors used are those suggested by Timaeus and Nuun (1997), to address the problems related to the specific age pattern of AIDS mortality increase.

[3] Children ignoring their mothers' whereabouts have been classified as maternal orphans.
[4] We use UNAIDS prevalence trends, and assume a vertical transmission of 0.25 and 20 per cent of fertility reduction of HIV positive women.

Figure 1: Levels of female ${}_{10}q_{25}$ derived from orphanhood data vs UNPD ${}_{10}q_{25}$ estimates



Bearing in mind the problems of data quality mentioned above as well as the possible over-estimation of mortality by UNPD life tables, the fact that model estimates are much higher than estimates obtained from orphanhood with conventional approaches is hardly surprising. The discrepancies are particularly strong for high levels of mortality; orphanhood estimates yield mortality levels which are systematically lower than 50% of the UNPD levels when ${}_{10}q_{25}$ is higher than 0.15. The second plot illustrate that this could be due to HIV-related biases, since revised coefficients and adjustments factors yield values that are a little more consistent with model estimates, although estimates still seem biased downward. In this connection, it is worth noting that HIV-related biases are higher for younger respondents (Timaeus and Nuun, 1997), and DHS data offer only two possibilities: reports from children aged 5-9 and children aged 10-14. In addition, the time location procedure suggested by Brass and Bamgboye (1981) requires proportions of respondents with parents alive for 10–year age groups, and is therefore limited to DHS reports from children aged 5 to 9.[5]

[5] The alternative procedure proposed by Palloni and Heligman (1985) requires only information for 5-year age groups.

Since no empirical gold standard exists to provide benchmarks allowing the joint analysis of parental loss and adult mortality in African populations, there is no straightforward way to distinguish between the three sources of discrepancies that we mentioned: (1) survey misreports, (2) model overestimation and (3) methodological assumptions underpinning the orphanhood method. In recent years, researches have mainly addressed the first two items. Simulation might be useful to have a closer look at the third one - the estimation methodology. Among other factors, the spread of HIV-AIDS and recent mortality reversals may have breached the basic assumptions of indirect techniques and especially the calculation of reference periods. In this communication, we suggest using micro-simulation techniques. Especially, the SOCSIM program, developed at Berkeley[6], simulates the process of demographic events while keeping trace of kin's identifiers. The proportion of surviving parents can therefore be observed rather than modeled, and that offers much more flexibility. [7]

Methods

Basically, we want to convert, adjust and time-locate the proportions of orphans recovered from simulation outputs under different contexts and then to compare them with deaths rates feeding the models. In this section we just briefly review both techniques: the orphanhood method and kinship micro-simulations.

The rationale of the orphanhood method is relatively simple. By the way of coefficients obtained from analytical models, the methods relates proportions of respondents with surviving parents (classified by the age of respondents) to survivorship probabilities (from the *mean age of parents at birth* to this age plus the respondent's age) (Timaeus, 1992). The method has not changed much since the 1970s, but new sets of coefficients have been suggested. Most of them are based on standard mortality age patterns and obtained under the assumption of population stability (United Nations, 1983; Hill and Trussell, 1977; Palloni and Heligman, 1985; Timaeus,

[6] http://www.demog.berkeley.edu/~socsim/c_doc.html, 15 September 2008

[7] A similar approach could have been followed with macro-simulation (e.g. Spectrum) but our objective is to extent the research to the estimation of overall and maternal mortality from sibling histories. Kinship microsimulation is therefore needed.

1992). Procedures developed to date the estimates when mortality has changed overtime have been designed for linearly declining mortality levels - captured either with a trend of the α parameter of Brass logit system (Brass and Bamgboye, 1981) or by an increasing trend in life expectancies (Palloni and Heligman, 1985).

As we mentioned above, the method has been recently revised to take into account the advent of HIV/AIDS. Timaeus and Nuun (1997) have suggested an adjusting factor to correct for two selection biases: the reduction in fertility of HIV-positive women (F) and the vertical transmission (h). This correction factor is applied to the observed proportion of orphans: ${}_5S_x' = \left[1-(1-(1-h)F)\times HIVprev\right]{}_5S_x$.[8] In addition, in settings affected by HIV-AIDS, adult deaths are concentrated in a narrow range of ages. Proportions of orphans therefore increase less rapidly as mortality rise than in other contexts. The probabilities of surviving tend to be over-estimated, particularly from reports of respondents aged 5 to 9 and 10 to 15, i.e. the age groups for which DHS data is available. Using data from the Masaka DSS (Uganda), Timaeus and Nuun (1997) have suggested new sets of coefficients to correct for that too.

In essence, micro-simulations assign events (deaths, birth, and marriage) to fictitious individuals using pre-defined vital rates. With SOCSIM, the closed-marriage model we use here, these events are allocated to individuals through event competition depending on waiting times specified as piecewise exponential (Wachter, 1995). In our micro-simulation set, we built one scenario for each mainland sub-Saharan country.[9] We use the non-AIDS UNPD life tables to model background mortality by country, and translate them into a Lee-Carter model, in order to allow SOCSIM to work with death rates which vary with time. The fertility age pattern is modeled with a Coale-Trussel model whose parameters (i.e the mean and standard deviation of age at first marriage, as well as the departure from natural fertility) are estimated from DHS surveys and UN

[8] This adjustment is halved for children aged 5 to 9 : ${}_5S_x' = \left[1-\frac{(1-(1-h)F)}{2}\times HIVprev\right]{}_5S_x$.

[9] Except for Rwanda and Sierra Leone, whose demographic paths have been heavily disrupted by wars and conflicts.

publications related to fertility and nuptiality (United Nations, 1988; United Nations, 2000).[10] Total fertility rates match smoothed UNPD estimates by year.

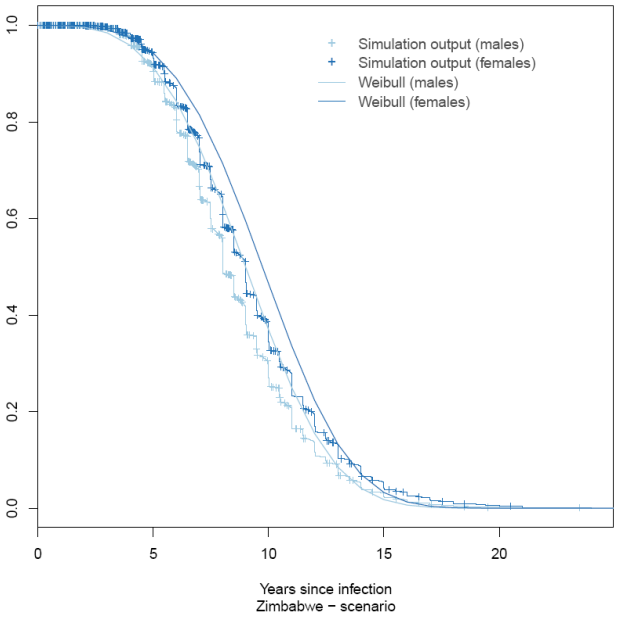
In the core program, no allowance is made for HIV-aids mortality, but different transitions rates can be set up from group to group with specific demographic rates. Therefore, we have used UNAIDS estimates of HIV incidence to derive infection rates (i.e. transition from group 1 HIV-seronegatives to group 2 HIV seropositives), together with the African age and sex-specific pattern of HIV infection (modeled as a Weibull distribution with mean age at infection of 32 for males and 27 for females). The HIV disease progression is then modeled as a staged process with 9 successive stages from HIV infection to full blown AIDS. For each sex, a constant hazard of transition between stages is assumed (independent of the previous state), as in a Poisson process, except that the final stage is absorbing (Aalen, 1995). The duration of the incubation period is therefore modeled as an Erlang distribution, which has been widely used in the AIDS literature (Tan, 2000). We opted for such compound exponential because it permits to work with age-invariant transitions rates trough stages, without relying on the time since infection (which is not recorded during the simulation). Once fixed a shape of 9, the rate of the Erlang distribution has been approximated numerically to provide a distribution function very close to the Weibull distribution used by the United Nations (2009) (Figure 2).[11]

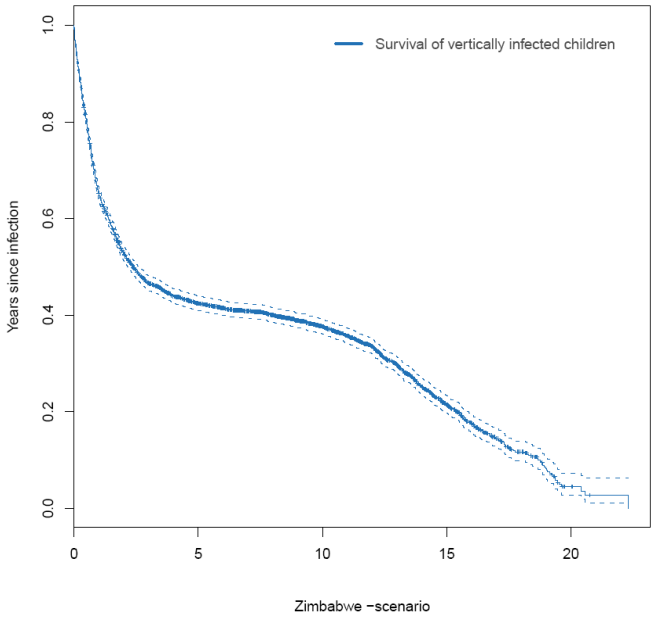
In addition, survival once reached the full blown AIDS stage is modeled through an exponential distribution with rate 1/2, yielding a mean survival time of 2 years. Perinatal HIV transmission is estimated at approximately 20-25%. Survival for mother-to-child infected individuals is derived from a double Weibul model (following Marston et al. (2005)). The mean survival for slow progressors is 15.2 years (42% of children) and 1.3 years for fast progressors (Figure 3). Fertility rates of HIV-positive women are reduced by a factor of 0.7.

[10] The parameters are obtained through a maximum likelihood estimation method described extensively in Rodriguez and Trussell (1980). The departure from natural fertility is estimated from DHS marital/general fertility rates with Poisson regression as detailed in Broström (1985). Parameters are smoothed by regions and interpolated for each segment of the simulation.

[11] At this stage, no allowance is made for the impact of ART.

Figure 2: Transition to full blown AIDS modeled as an Erlang distribution with shape 9 (Zimbabwe simulation outputs)
Figure 3: Survival of children infected vertically (Zimbabwe simulation outputs)





For each country, the different simulations start in 1900 under conditions of stability until 1950, and deaths and birth rates then vary until 2007. The size of the starting population (in 1900) is calculated to yield a final population of approximately 30000 surviving individuals at the end of the simulation. In order to reduce the random variability, each scenario is replicated 10 times, and final populations are merged by country. After completion of the micro simulations, we use event history analysis to extract death rates, fertility rates, orphan prevalence as well as transition probabilities through HIV-related groups from the simulation outputs. Adult mortality levels are then re-estimated with the orphanhood method.

Even if different assumptions are used with respect to the demographic impact of HIV-aids (as for perinatal transmission, impact of ART, etc.), the re-estimated deaths risks obtained from the micro-simulations are consistent with UNPD estimates, as can be shown with the case of Zimbabwe, with female e_0 (Figure 4), ${}_{45}q_{15}$ (Figure 5) and ${}_{5}q_{0}$ (Figure 6).

Figure 4: Life expectancies at birth fetched from the simulation results and estimated by UNPD – Zimbabwe (males)

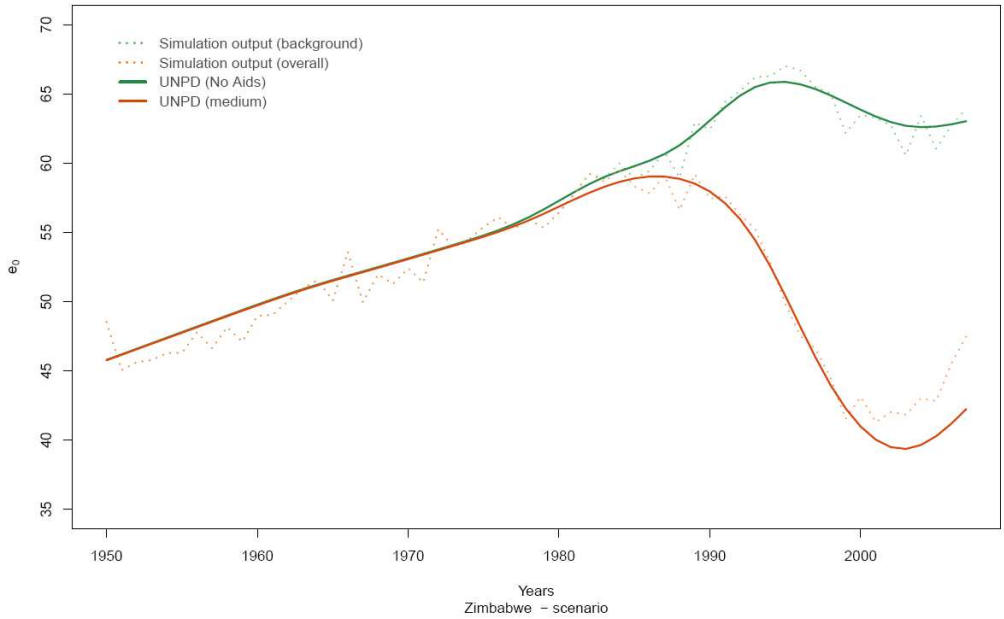


Figure 5: Adult mortality (${}_{45}q_{15}$) fetched from the simulation results and estimated by UNPD – Zimbabwe (males)

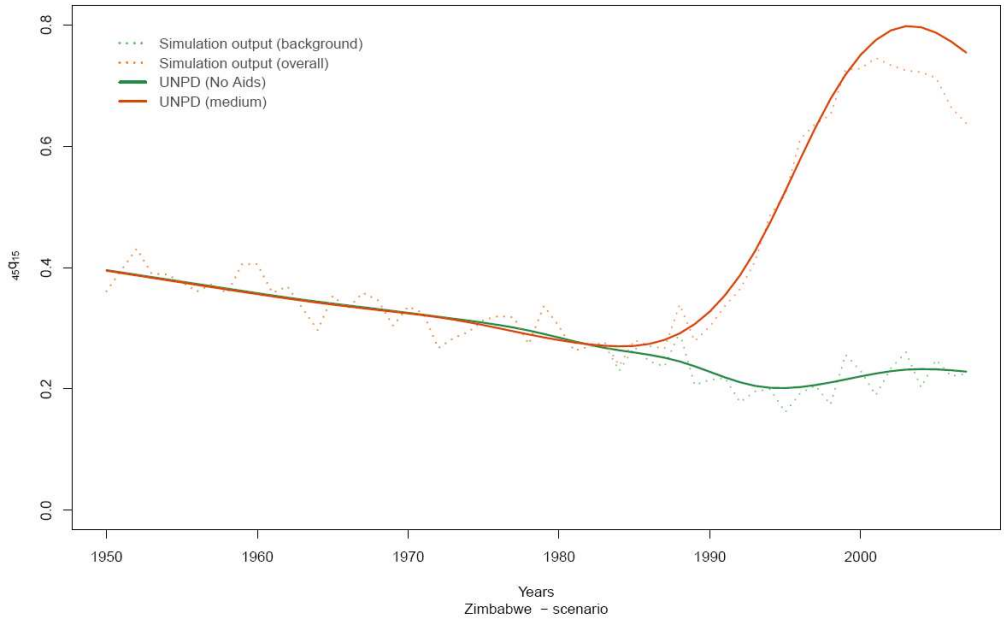
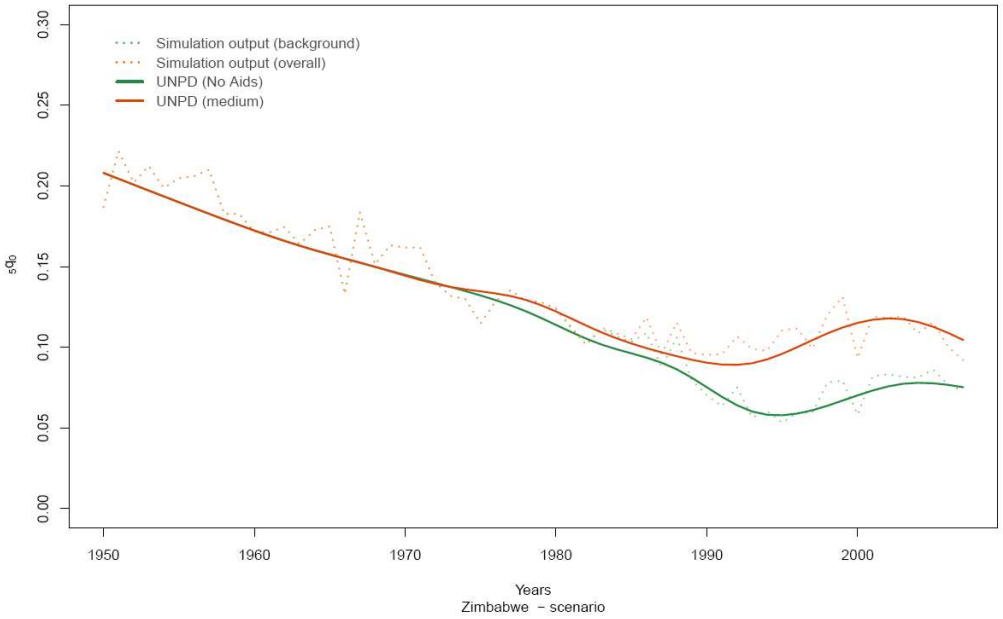


Figure 6: Child mortality ($_5q_0$) fetched from the simulation results and estimated by UNPD – Zimbabwe (males)

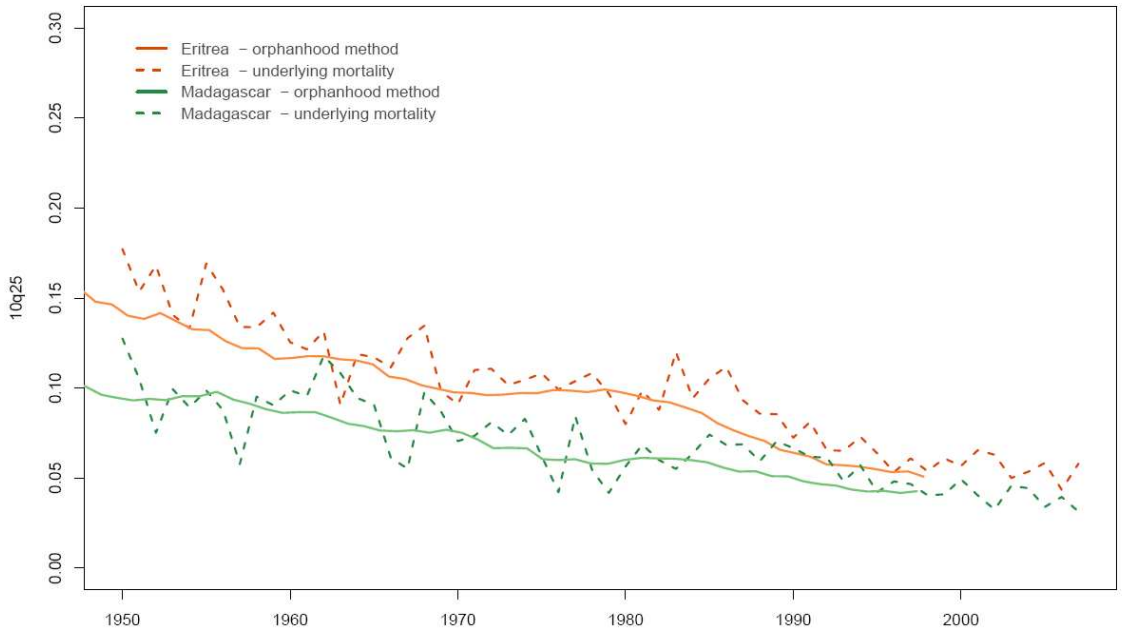


Results

As we can take successive censuses during the simulation, the orphanhood method can be applied to reports of respondents for each annual interval (as if a survey or census was available on an annual basis for a given country). Each estimate can be time-located, in order to reconstruct a trend of observed mortality from kin survivorship. This trend can then be compared with the mortality patterns that produce it.

Firstly, coefficients are taken from Timaeus (1992) and the time location procedure is taken from Brass and Bamgboye (1981) (Figure 7). Since re-estimated probability of death are based on reports of children aged 5-9 only, the trends are for mortality from age 25 to 35. Figure 7 illustrates the congruence of estimates derived from orphanhood and underlying death risks in countries where mortality changes have been approximately linear. Two scenarios are presented here: Madagascar and Eritrea. In both cases, the re-estimated trend from parental survivorship reproduces faithfully the trend of the underlying mortality.

Figure 7 : Trends in underlying female ${}_{10}q_{25}$ and ${}_{10}q_{25}$ re-estimated with the orphanhood method – Burkina Faso and Madagascar scenarios (time location procedure : Brass & Bamgboye 1981).



We now turn to populations experiencing severe HIV epidemics and rapid mortality reversals, with the example of Zimbabwe and Uganda.

provides illustrative evidence that in this case, orphanhood-based estimates can depart significantly from the underlying mortality that produce them. Re-estimated death rates from kin survivorship statistics fail to capture the rapid increases of underlying death risks. In Figure 9, orphan prevalence has been adjusted for HIV-related selection biases (Timaeus and Nuun, 1997), but orphanhood estimates then tend to depart even more from the underlying mortality in the first years of the epidemic. In Figure 10, revised coefficients for HIV settings are used when HIV prevalence is above 1%.[12]

[12] For the sake of clarity, the Zimbabwean scenario is not plotted since it gives a similar picture.

Figure 8 : Trends in underlying female ${}_{10}q_{25}$ and ${}_{10}q_{25}$ re-estimated with the orphanhood method – Zimbabwe and Uganda scenarios (time location procedure : Brass & Bamgboye 1981).

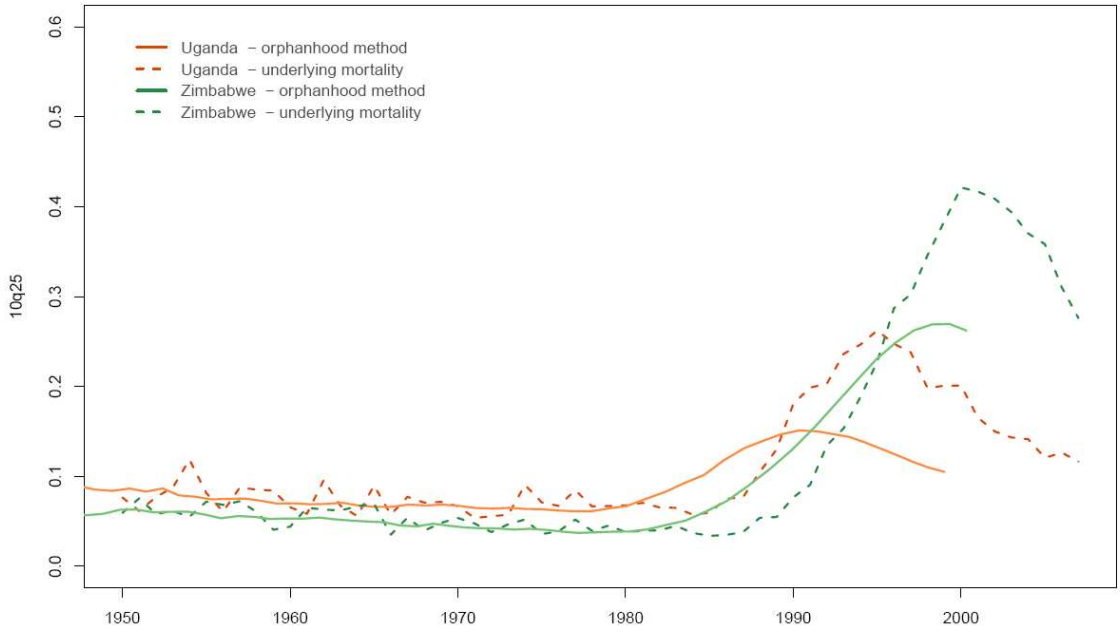


Figure 9 : Trends in underlying female ${}_{10}q_{25}$ and ${}_{10}q_{25}$ re-estimated with the orphanhood method with adjustment for HIV-related biases – Zimbabwe and Uganda scenarios (time location procedure : Brass & Bamgboye 1981).

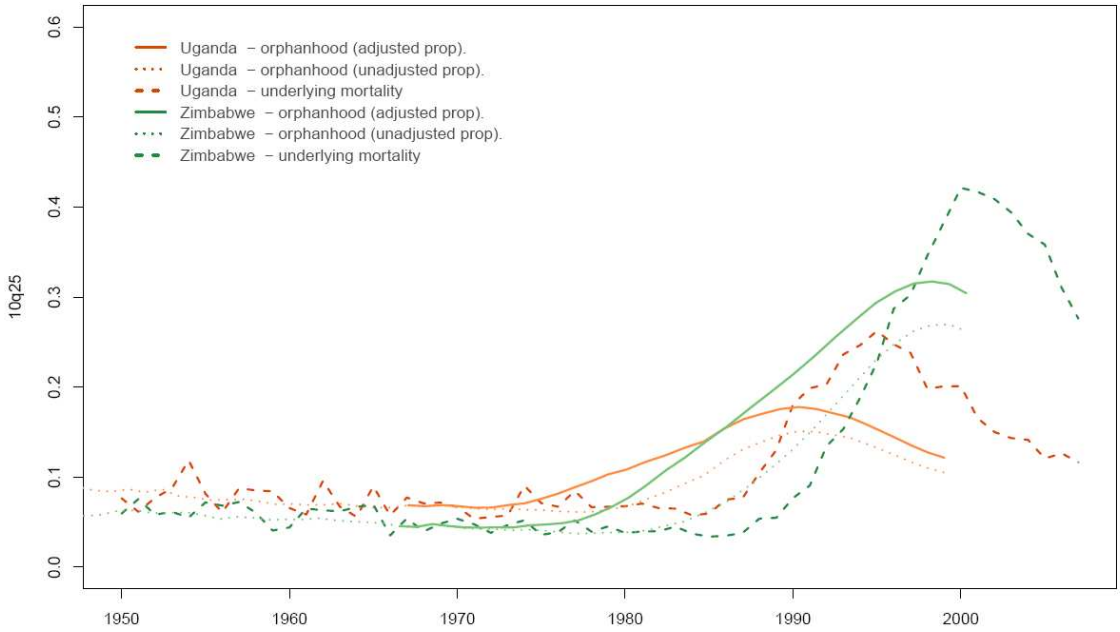
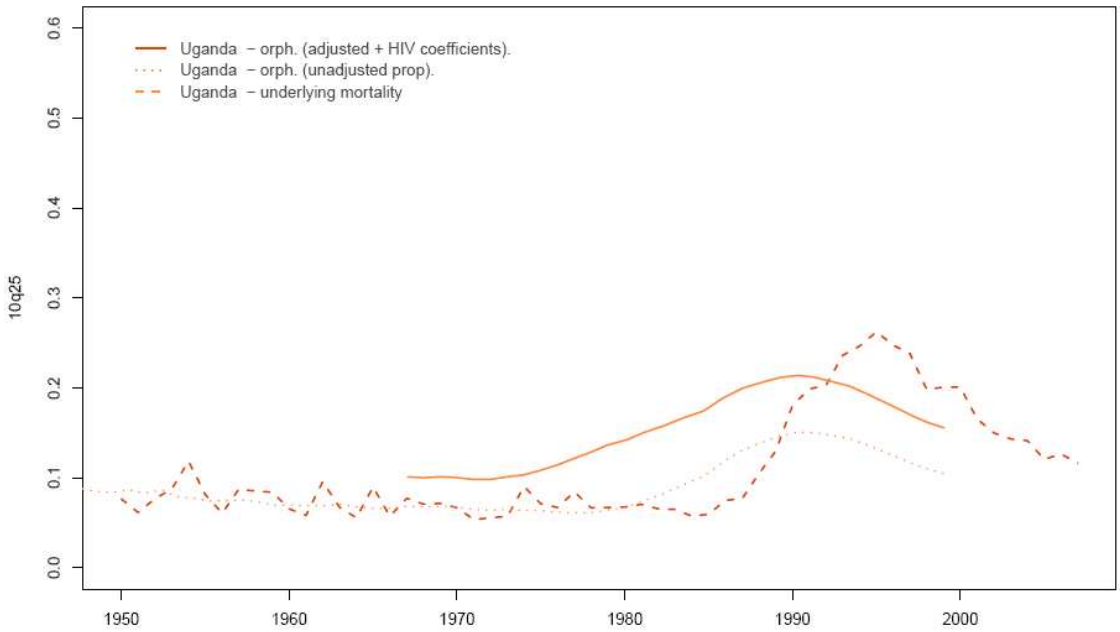


Figure 10 : Trends in underlying female ${}_{10}q_{25}$ and ${}_{10}q_{25}$ re-estimated with the orphanhood method – with adjustment for HIV-related biases and revised coefficients for HIV settings - Uganda scenario.



Timaeus and Nuun (1997) have shown that HIV-related selection biases should be fairly small because they are unlikely to select out more than half of the reports of infected women. They also pointed out that "the derivation of the correction factor suggests that it should be valid whatever the level of background mortality or seroprevalence." In fact, the main breach in assumptions underlying the method is likely to stem from limitations of time location calculation methods. Feeney (2001) has already noted that the dating procedure may lack of robustness in cases of rapid mortality reversals. Due to the HIV epidemic, the linearity of mortality trends clearly does not hold. Although it locates estimates further back in time, the procedure developed by Palloni and Heligman (1985) performs no better than the Brass procedure (results not shown).

Usually, only a few censuses or surveys are available by country. The reports on survivorship of parents for different age groups of respondent are then used to provide a clue for the assessment of trends. But the issue of the selection of an appropriate model life table then needs to be addressed, especially in HIV settings. For now, no available model life table can be used for that purpose, except for the INDEPTH model life tables.

Use of synthetic cohorts and rate of increase in parental survival

The use of synthetic cohorts allows us to by-pass the difficult task of time location estimation (Zlotnik and Hill, 1981; Timaeus, 1986) . Zlotnik and Hill (1981) have suggested a technique to "chain" together changes experienced by a given age *cohort* during the intercensal or intersurvey period. Alternatively, Preston (1983) shows how changes experienced by a given age *group* between two censuses or surveys can be used instead. In this case, a correction factor based on the growth rate of the proportion non-orphaned removes the impact of past trends. The observed proportions of non-orphans in two different sets of orphanhood data yield an adjusted proportion that pertains to the intercensal period and would be observed in a stationary population (based on the intensity of mortality during this period). An extensive description of the method is provided in Preston et al. (2001).

We apply this technique to proportions of non-orphaned computed from the microsimulations for 5-years interval, and for the cases of Uganda and Zimbabwe. Adjusted proportions are then converted with coefficients proposed by Timaeus (1992) when HIV prevalence is under 10%, and Timaeus and Nuun (1997) coefficients once HIV prevalence has reached 10%. HIV-related selection biases are also taken into account with the correction factor previously mentioned.

As can be seen from Figure 11 and Figure 12, in both cases, the combination of (1) correction factors removing the impact of past trends and (2) revised methods addressing the specific problems posed by HIV-aids yields estimates much more consistent with the mortality underlying the simulations than estimates based on a single one of these two kinds of adjustments. In settings heavily affected by HIV-aids, it seems that such combination should therefore be recommended.

Figure 11 : Trends in underlying female ${}_{10}q_{25}$ and ${}_{10}q_{25}$ re-estimated with the orphanhood method and different options –Zimbabwe scenario.

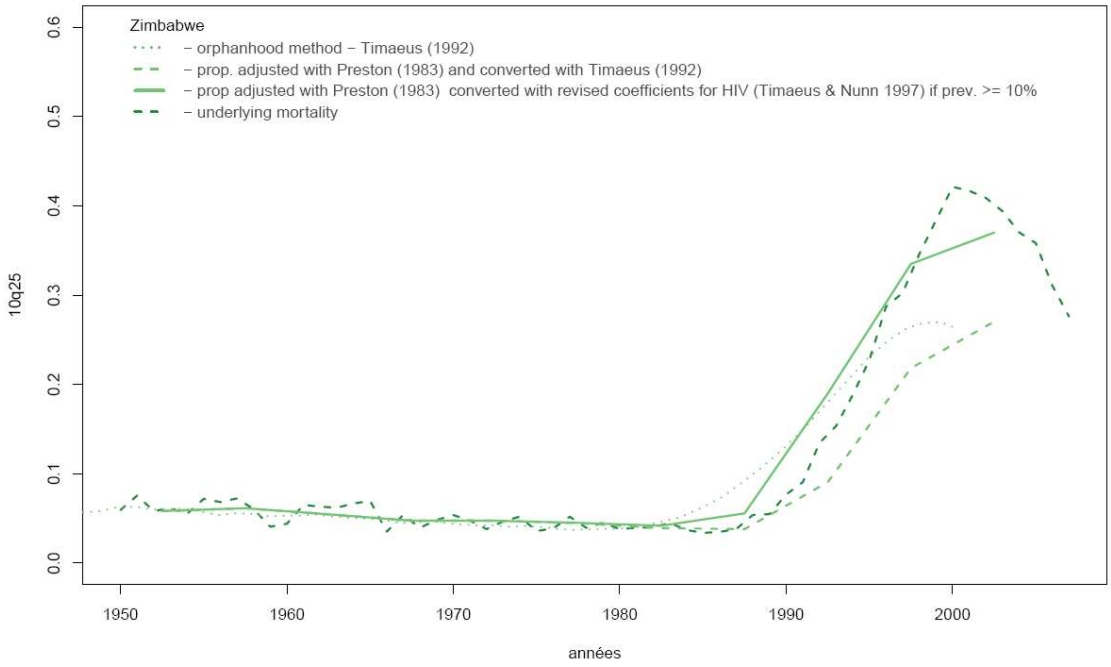
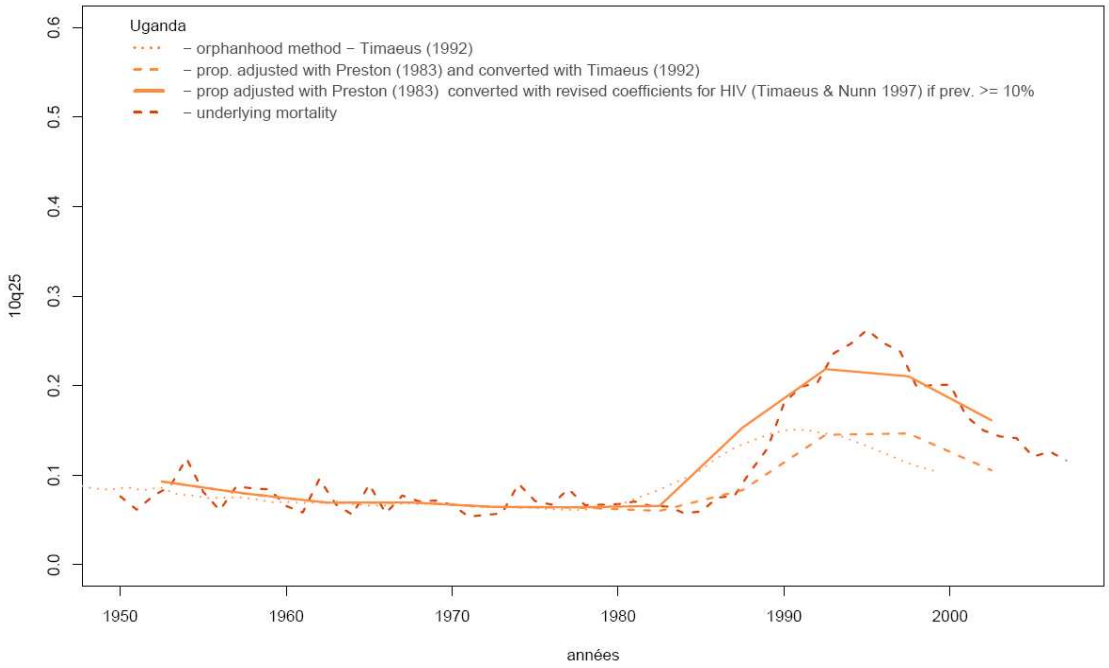


Figure 12 : Trends in underlying female ${}_{10}q_{25}$ and ${}_{10}q_{25}$ re-estimated with the orphanhood method and different options - Uganda scenario.



Conclusion

The use of micro-simulation techniques yields new insights into the strengths and limitations of indirect methods based on the survival of the respondents' close relatives. Micro-simulations can reproduce the demographic dynamic of various sub-Saharan countries on populations of fictitious individuals whose kinship networks are recorded. Of course, they are only as accurate as the assumptions and estimates on which they are based. But they permit to control for problems of data quality as well as issues related to the fact that we generally ignore the underlying mortality level. Since they provide benchmarks for mortality rates as well as orphanhood prevalence, they can serve as a useful tool to assess the validity of the assumptions on which kin survivorship methods are based and even to estimate the size of biases when those assumptions are breached.

We showed here that a simple application of orphanhood method to HIV settings may produce over-estimation of mortality in the first years of the epidemic and then a substantial underestimation of mortality risks as the epidemic grows in age, even with revised coefficients. But the combination of adjustments to control for past trends and HIV biases can yield more reliable estimates.

Our results are still explanatory and a more extensive study of the potential of microsimulations for such purpose should be completed along the lines suggested here. It is especially needed to develop ways to estimate the reference times when only a few surveys or censuses are available in countries affected by HIV/AIDS. For instance, the ratio of proportion of orphans in two successive age groups could be used. The time location procedure could also incorporate information on the estimated HIV incidence trends.

This analysis should also be extended to paternal orphanhood (for which there is currently no set of coefficients for HIV settings), as well as to sibling data, the second broad type of indirect technique based on kin survivorship. Especially, the widely used sisterhood method for maternal mortality could be reviewed with the same tool.

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