Estimates of HIV Incidence Profiles for sub-Saharan Africa with Projected Declines in Fertility

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1 INTRODUCTION

As HIV epidemics mature across sub-Saharan Africa the demographic features of these countries are changing considerably. Mortality is increasing among young and middle-aged adults (Timaues and Jasseh, 2004), groups who tend to have much lower mortality rates in countries with zero or low prevalence. It is also known that HIV lowers fecundability Carpenter et al. (1997); Fylkesnes et al. (1998); Gray et al. (1998); Kigadye et al. (1993); Kilian et al. (1999) which suggests downward pressure on fertility in countries with high HIV prevalence. Terceira et al. (2003) have estimated that HIV is associated with a quarter of the fertility decline in rural Zimbabwe during the 1980s. Given this results, it is interesting to ask what the affect will look like in other parts of Africa. Particularly since the relationship between fertility and HIV depends on the size of the epidemic, which varies drastically across regions of Africa, as well as the age of the epidemic, since fecundity impairment becomes more severe as the time since infection increases.

In this study we explore the impact of the HIV epidemic on total fertility for countries in sub-Saharan Africa. Data on HIV prevalence from the Demographic and Health Surveys (DHS) are used to estimate age profiles in HIV incidence for several geographic regions using a multi-state cohort-component model for population projection developed by Heuveline (2003), namely CCMPP. This model incorporates important links between the demographic and epidemiological components of population growth and disease spread. In particular, sub-fecundity among HIV infected women, conditional on time since infection, is explicitly included in the model. This allows us to assess the influence on fertility by comparing population projections to simulations where there is no sub-fecundity experienced by HIV positive women. It is crucial that CCMPP partitions the population into five-year age groups since fertility, incidence, and the age distribution are all dependent on age.

2 LITERATURE REVIEW

There are various mechanisms through which HIV/AIDS affects fertility among women. Terceira et al. (2003) review these pathways and highlight both behavioral and biological factors that can influence fertility. For example, women who perceive themselves to be at a

high risk of infection may choose to limit sexually activity or adopt condom use to reduce the probability of transmission, both actions that would lower fertility (for as long as these strategies are followed). One might speculate that the size of this affect may change over time as the size of the HIV/AIDS epidemic grows, resulting in more visible evidence of people becoming infected (and dying) and perhaps more information regarding the risk of infection circulating in social networks. Other socio-demographic factors include an increased risk of divorce and widowhood, which may be more prominent among discordant couples where one partner is infected and the other is not. There is also evidence that HIV/AIDS decreases fecundity and fertility via increased amenorrhoea, foetal wastage and stillbirths (Carpenter et al., 1997; Fylkesnes et al., 1998; Gray et al., 1998; Kigadye et al., 1993; Kilian et al., 1999; Zaba and Gregson, 1998). Previous work also suggests that the reductions in fertility increase as the time since infection increases, and thus we might suspect larger declines in total fertility as an HIV/AIDS epidemic matures and more HIV+ women (especially those infected at young ages) age into states of longer duration of infection (Heuveline, 2003).

Many of the studies in this area use the population attributable change (PAC) in fertility rates to assess the size of the impact. Conditional on the assumption that fertility in the absence of HIV/AIDS is reasonably approximated by fertility among the HIV-negative population, the PAC in fertility can be calculated as: (fertility in the total population - fertility in HIV-negative population)/fertility in HIV-negative population (Zaba and Gregson, 1998). Zaba and Gregson (1998) estimate that a percentage point increase in HIV prevalence is associated with a 0.4 decrease in the PAC in total fertility. In other words, a population with 20% HIV prevalence is expected to have a TFR that is 4% lower than a population with 10% HIV prevalence, all else being equal (e.g. fertility in the absence of HIV/AIDS). Using data from various sources across sub-Saharan Africa, Lewis et al. (2004) estimate that a percentage point increase in HIV-prevalence is associated with a decline in the PAC in total fertility of 0.37. In a study conducted in Manicaland, Zimbabwe, Terceira et al. (2003) estimate the PAC in age-specific and total fertility. The authors of that study find a reduction in the TFR of 9.9%[1] among sexually experienced and currently married women, respectively. Among women who are sexually experienced, the largest changes occur for those in their thirties.

Heuveline (2003) uses an interesting approach to assess the impact of HIV/AIDS on fertility which involves one of the classic methods for making population projections, namely the cohort-component method. Heuveline modifies this method by adding additional states for people in the projected population who are HIV-positive. This model also captures some of the links between fertility and HIV infection by parameterizing the reduction in fertility

[1]The value may actually be 7.6% because of a potential error in the calculations given the numbers in Table 5, p 159.

as a function of time since HIV infection (for more details, see Heuveline, 2003; Thomas and Clark, 2008). With a projected population classified by age and HIV status, one can calculate the PAC for age-specific fertility rates (ASFRs) and the total fertility rate (TFR), as well as other fertility measures. Using data compiled from countries in eastern Africa Heuveline (2003) projects a PAC in total fertility of 1.2%, 5.0%, 9.8%, and 9.6% for 10, 15, 20, and 25 years after the HIV epidemic began (see Table 4, p. 236).[2] We build on the work by Heuveline (2003) by using his cohort-component model for population projection (CCMPP) to assess the impact of HIV/AIDS on fertility on other regions of sub-Saharan Africa. Since the publication of the model, more information on age-specific HIV prevalence has become available via the Demographic and Health Surveys (DHS). We use these data to estimate model parameters, and project the PAC in ASFRs and in total fertility separately for countries in central, eastern, southern and western sub-Saharan Africa. Heuveline (2003) proposes a maximum likelihood for parameter estimation with his model, but we follow a different path and use a Bayesian framework for estimating and projecting. The primary motivation for our approach, namely Bayesian melding (Poole and Raftery, 2000), is that it allows us to assess the uncertainty in both the parameter estimates as well as the projected PAC in fertility. Given the complex nature of HIV and population dynamics, it is particularly important to include measures of uncertainty.

3 METHODOLOGY & DATA

We adopt the following strategy to assess the impact of HIV on total fertility. First, we use DHS data on age-specific HIV prevalence to estimate the parameters in Heuveline's multi-state CCMPP (Heuveline, 2003). Separate estimates are made by pooling data in different regions: central (Cameroon, CAR, and DRC), eastern (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe), southern (Lesotho and Swaziland), and western (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Guinea, Liberia, Mali, Niger, and Senegal) sub-Saharan Africa. We present the parameter estimates related to the age pattern of HIV incidence for each region, as well as the residual plots comparing the observed level of HIV prevalence to our projections. Given these estimates, we then project the population in each region and calculate the PAC in the ASFRs and the TFRs for the period thirty years after the epidemic began in that specific country. The CCMPP model is described in more detail in the next section, as well as the Bayesian melding (Poole and Raftery, 2000) approach used to carry out the parameter estimation and the population projections.

[2]The corresponding projection for adult female HIV prevalence are 12.5%, 22.6%, 24.0%, and 21.%.

3.1 Projection Model

The PAC in age-specific fertility rates is used to demonstrate the affect of HIV on fertility. The CCMPP by Heuveline (2003) has the added benefit of projecting a population classified by the duration of HIV infection for five-year groups. The age-specific fertility rate of each duration group is reduced by a multiplicative factor that depends upon the duration of infection. Let $f_{a,t}$ be the fertility rate for HIV-negative women in (5-year) age group a at (5-year) time interval t. The fertility rate for women in age groups between 20 and 49 years and who have been infected for less that five years (as modeled in Heueveline's CCMPP) is

$$f_{a,t,d=5} = f_{a,t} * g_{d=5}, \tag{1}$$

where $g_{d=5}$ is the HIV-associated impairment in fertility for those infected for less than five years; and similarly for women (of all age groups) who have been infected for 5-9 years ($d = 10$) and 10-4 years ($d = 10+$). The fertility rate for HIV-positive women aged 15-9 who have been infected for less than 5 years ($d = 5$) is

$$f_{a=15-9,t,d=5} = f_{a=15-9,t} * g_{d=5} * e, \tag{2}$$

where e is the (expected) multiplicative increase in fertility associated with higher sexual activity (and thus higher risk of both infection and fertilty) among women in this age group. This parameter is expected to be greater than one, while the fertility impairment parameters are expected to be less than one.

In our application of the CCMPP, we set the age-specific fertility rates for uninfected women from the United Nations projections (United Nations, 2007) and treat them as fixed. The fertility impairment ($g_d,\ d = 5, 10, 15+$) and selection (e) parameters are estimated from data, compiled by Heuveline (2003), which consist of the number of children born to both HIV-positive and HIV-negative women (by age group) in cohorts sampled from the population in Uganda (Carpenter et al., 1997; Gray et al., 1998).[3]

3.2 Parameter Estimation

We adopt a Bayesian approach to parameter estimation and carry out statistical inference using a sample from the posterior distribution of each parameter. The model parameters can be described as inputs which (deterministically) produce a set of CCMPP outputs, i.e. projected counts. This can be expressed by letting M represent the CCMPP model which transforms a set of parameter inputs, θ, into a set of outputs, $\phi = M(\theta)$. If our prior density

[3]Observed HIV-prevalence for women who attended antenatal clinics and data on mother-to-child transmission also contribute information to the estimates of the fertility impairment and fertility selection parameters. For more details, see Heuveline (2003); Thomas and Clark (2008).

for the model inputs is $p(\theta)$, then we can use Bayesian melding to combine these prior beliefs with a likelihood, $\mathcal{L}$, for the model and the data, $\mathbf{y}$ (Poole and Raftery, 2000). These pieces of information are combined in the usual way to produce a posterior distribution that is proportional to the likelihood times the prior density

$$p(\theta|\mathbf{y}) \propto \mathcal{L}(\mathbf{y}|M(\theta))p(\theta). \tag{3}$$

To carry out inference on $p(\theta|\mathbf{y})$ we draw a random sample using an incremental mixture importance sampling (IMIS) algorithm optimized to work in high dimensional space (cite other papers). The multi-state version of CCMPP has 33 parameters, for which we specify independent, uniform priors. For our purposes here the focus is restricted to the parameters directly related to fertility, i.e. the fertility selection and fertility impairment parameters described above. Recall that the fertility selection parameter is the multiplicative factor by which fertility is higher among women aged 15 to 19 because of higher sexual activity. This is consistent with the finding by Terceira et al. (2003) fertility is higher among currently married women who are both HIV-positive and between the ages of 15 and 19. We use a uniform prior bounded between 1 and 5 for the fertility selection parameter, which is meant to reflect the large amount of uncertainty about how large the fertility differential is. For the fertility impairment parameters, we use a uniform prior with endpoints of zero and one, i.e. the natural boundaries of a proportion. The data used to update our prior beliefs take the form of proportions[4] which makes the binomial distribution the natural choice for the likelihood. For more details see Thomas and Clark (2008).

4 RESULTS

4.1 Parameter Estimates

In the next two sections we present parameter estimates for the age patterns in HIV incidence and the estimates for the CCMPP model parameters which relate HIV to fertility. In the former, age patterns are presented by region (central, eastern, southern, and western), along with a residual plot depicting how close the projections are to the levels observed in the DHS data.

[4]The fertility impairment and selection parameters are estimated from data, compiled by Heuveline (2003), which consist of the number of children born to both HIV-positive and HIV-negative women (by age group) in cohorts sampled from the population in Uganda (Carpenter et al., 1997; Gray et al., 1998). Age-specific estimates of HIV prevalence are also used; see Thomas and Clark (2008) for more details.

4.1.1 Age Profiles for HIV Incidence

The following series of figures include a set of two plots for each region in sub-Saharan Africa. The first plot shows the estimated relative HIV incidence ratio (taken as the median of the posterior sample) for men and women, by age group. The age patterns for females (males) are plotted with an F (M) with the color black (gray). The dashed lines extending from the estimated median span the 95% credible interval. The second plot (in the set for each country) shows the age-specific residuals for each country that we made projections for. The actual numbers on the plot indicate the lower bound of the five-year age group, and women are shown first in black, then men in gray. The sets of these two plots will now be discussed for central, eastern, southern, and western sub-Saharan Africa (in that order).

There are three countries that contribute DHS data from the central region: Cameroon, CAR, and DRC. While the age pattern for females (see Figure 1) appears to peak among women in their twenties, there is too much uncertainty around the point estimate to be able to identify signficant differences between the age groups. The same can be said for men, except that incidence may be lower at the younger ages, relative to the older ages. The residuals for central Africa are shown in Figure 2. Most of the projections fall within two percentage points above or below the value observed in the DHS. There are, however, some larger negative residuals among men, particularly in the CAR.

The age profiles of HIV incidence estimated using DHS data from eight countries in eastern Africa are shown in Figure 4. For this region, there is a peak for women in their late-twenties and early thirties, with a decline among the older ages. There is a similar pattern among men, but relative incidence at younger ages is substantially higher among women. It should also be pointed out that the large amount of uncertainty around the point estimates for men at older ages makes it difficult to judge if there is a clear decline in th relative risk of incidence during these years (for men). This is primarily due to the sharp drop in the relative incidence ratios for men between the age groups of 40-4 and 45-9 years.

The residuals associated with the projections for eastern Africa are plotted in Figure 4. There are several residuls which are either four percentage points above or below the observed level indicated by the DHS data. There do not appear to be any systematic patterns my age, gender, or country.

DHS data on age-specific HIV prevalence from Lesotho and Swaziland are used to estimate the regional pattern from southern Africa (see Figure 5). The estimates show an earlier peak in HIV prevalence for women, which occurs among those aged 20-4 years old. The peak among men occurs among those aged 30-4 years, and we again find that relative HIV incidence tends to be lower among men in the younger age groups compared to women. Figure 6 shows the residual plot for southern Africa, where there are several errors as greater

than five percentage points (in absolute value). The residuals are especially large for women in Lesotho.

Finally, the age patterns estimated for western Africa are shown in Figure 7, which were obtained using DHS data from nine countries. As is the case for central Africa, where HIV prevalence also tends to be lower, there is too much variation in the age-specific estimates to detect any clear pattern. The length of the 95% credible intervals are particularly wide among men in their fifties. There is, however, the general finding that relative HIV incidence is lower for men, relative to women, in the younger age groups. In the residual plot in Figure 8, we see that the the projections for western Africa primarily fall within two percentage points above or below the value observed in the DHS data. There are some larger errors among females in Côte d'Ivoire, but these the only exceptions. It should also be noted that the relatively small residuals are expected given the lower levels for age-specific HIV prevalence in western Africa.

4.1.2 Fertility Selection and Impairment Parameters

The samples from the posterior distributions of the CCMPP parameters related to fertility, obtained via the optimized IMIS algorithm, are presented in Figures 9 and 10. The posterior sample for the fertility selection parameter (see Figure 9) places most of the weight above the value of one, with a posterior mean of 1.85. This suggests that HIV-positive women between the ages of 15 and 19 years have fertility that is 85% higher than HIV-negative women in the same age group. The 95% credible interval (dashed, vertical lines) ranges from the lower end of roughly 1.4 to a higher bound of nearly 2.4.

Histograms of the posterior samples for the three the fertility impairment parameters, i.e. HIV+ women who have been infected for less than five years (top panel), women who have been infected for five to nine years (middle panel), and those who have been infected for more than ten yearsare shown in Figure 10. For the shortes duration group there is a considerable amount of weight placed near the upper bound of one, but the center of the distribution is roughly 0.85 and the lower end of the 95% credible interval 0.70. Fertility among women in the other two HIV duration groups is relatively much lower, with most of the distribution falling below a value of 0.5. The median and 95% credible interval of the posterior sample for the impairment parameter applied to women infected for five to nine years are 0.28 and (0.060, 0.527); and the corresponding numbers for the longest HIV duration group are 0.34 and (0.029, 0.787).

These posterior samples can be used to produce estimates of PAC for total fertility by using the specification of fertility appearing in Equations 1 and 2. The variation in the posterior samples translates into uncertainty around the level of age-specific fertility for

HIV-positive women. Fertility for the total population is simply the weighted average of the fertility rates for women in the different duration groups with the weights being the relative population share for each group. Thus, projected prevalence is negatively associated with the fertility in the total population. In the next section we present projections of the PAC in the ASFRs and in total fertility, by region, for the period that is thirty years since the HIV epidemic began.

4.2 HIV Associated Decline in Fertility

To assess the impact of HIV on total fertility, we calculate the PAC in the ASFRs and the TFRs using projections made for the various countries for which we have DHS data on HIV prevalence. The populations are projected 30 years into the epidemic, at which point the PACs are calculated. The findings for each region will now be discussed in turn.

4.2.1 Estimates of PAC in Fertility for Central Africa

The PAC estimates for countries in central Africa are shown in Table 1, where the first column indicates the particular age group or the TFR. To illustrate available information from Heuveline's CCMPP projection model, the estimates of HIV prevalence are shown for each age group and for two HIV duration groups: 1) HIV-positive women infected over less than five years ago, and 2) women infected more than four years ago. This information, along with the PAC, is presented for each of the three countries (Cameroon, CAR, and the DRC). Recall that it is important to classify the population by time since infection because fertility is estimated to decline as duration with HIV increases (see Figure 10). The numbers in parentheses are the 95% credible intervals that reflect the uncertainty around the estimated parameters.

In central African countries for which we have DHS data, the affect of HIV on fertility is fairly small. For example, the levels of HIV in Cameroon are projected to decrease the TFR by 3.2%, with a 95% credible interval ranging from a decline of 3.9% to a decline of 2.5%. Among the particular age groups, women aged thirty to thirty-four years are projected to have the largest decline 4.9% (95% CI: 6.1 – 3.5%). For this age group, just over six percent of women are estimated to have been infected with HIV for more than four years (95% CI: 5.6 – 7.7%). The age patterns for CAR and the DRC are very similar to that projected for Cameroon, but the levels are somewhat different. In the DRC, the affect of HIV on fertility is much smaller with a projected -0.7% (95% CI: -0.9%, -0.5%) for the PAC in total fertility. The level for CAR is slightly higher, compared to Cameroon, with a PAC in total ferility of -3.7% (95% CI: -4.4%, -2.9%).

4.2.2 Estimates of PAC in Fertility for Eastern Africa

Table 2 presents the projected PAC in total and age-specific fertility for eight countries in eastern Africa with DHS data on HIV prevalence. This table (and the following) differ slightly from the previous in that it does not include the projected HIV prevalence by age and HIV duration group. The results for this region differ from central Africa in that the impact of HIV on fertility is largest among women aged 35-39 (as opposed to 30-4 for central Africa). There are also several countries where the impact is much larger. For example, the TFR in Zambia is projected to be 8.2% lower compared to what is assumed to have happened in the situation where this is zero HIV prevalence. Zimbabwean women aged 35-9 have a projected PAC in their fertility of -17.4% (95% CI: -21.0%, -12.8%). There are, however, several countries where HIV plays a fairly small roll in reducing total fertility, as is the case for central Africa. These countries include Ethiopia, Rwanda, Ugnda, and Kenya. The corresponding estimates of the PAC in total fertility for these countries are -0.8%, -1.4%, -3.3%, and -3.4%.

4.2.3 Estimates of PAC in Fertility for Southern Africa

There are only two countries in southern Africa, Lesotho and Swaziland, with DHS data available on HIV prevalence at the time of this analysis. The projected impact of HIV on fertility estimated from these data are presented in Table 3. For both of these countries, the impact of HIV on fertility is projected to be much larger than for the other regions. The affect is largest among women aged 30 to 34, with an estimated PAC of 21.8% (95% CI: -27.0%, -14.7%) and -25.6% (95% CI: -31.7%, -16.9%) for Lesotho and Swaziland, respectively. Similarly, the TFR is projected to be 14.2% (95% CI: 17.0%, 11.2%) lower in Lesotho, and 18.0% (95% CI: 21.4%, 14.0%) lower in Swaziland.

4.2.4 Estimates of PAC in Fertility for Western Africa

Projections in the PAC of total and age-specific fertility for countries in western Africa are presented in Table 4. HIV prevalence in this region is so low that the reduction in total fertility is generally in the area of a 1% decline. The impact is estimated to be the largest in Côte d'Ivoire, Ghana, and Burkina Faso where the estimated PAC in the TFR is -2.7% (95% CI: -3.3%, -2.1%), -1.3% (95%CI: -1.6%, -1.0%), and -1.1% (95% CI: -1.4%, and -0.8%), respectively. The impact of HIV on fertility slowly increase up to age 35 to 39 years, and then declines slighty among women in their fourties.

5 DISCUSSION

In this paper, we assess the impact of HIV on fertility at the population level by using population projection model designed for the context of HIV/AIDS Heuveline (2003). We use DHS data in a Bayesian framework to estimate the parameters in the model that relate to the age pattern of HIV incidence. Separate estimates are presented for central, eastern, southern, and western sub-Saharan Africa. We find that a strong age pattern only emerges in eastern and southern Africa where the level of HIV prevalence is much higher, compared to the other regions. Residual plots are also included to help assess how well the Heuveline's model fits the DHS data. Generally speaking, the projections fall within four percentage points above or below the level observed in the DHS data. Given the complexity of HIV and population dynamics, we feel the model does a reasonable job of projecting these populations, but there is a lot of room for improvement.

The parameter estimates obtained from the DHS data are combined with estimates obtained from data originally compiled by Heuveline (2003) are used to project the population-attributable change in age-specific and total fertility rates for each country. The use of Bayesian melding (Poole and Raftery, 2000) allows us to include measures of uncertainty around all of the model outputs, including the PAC in fertility. Our results show a fairly wide range in the size of the impact of HIV on fertility, starting with a relatively small affect in most of western Africa (declines in the TFR of 0.3% to 2.7%), while reaching declines of up to 18% in southern Africa. The finding in southern Africa is partially driven by the age pattern in HIV incidence, which is estimated to peak among women in their early twenties. As the time since infection increases, these women experience even greater reductions in fertility during their primary, childbearing years. Our results also show a fairly large impact in several east African countries as well.

We conclude with a brief discussion of Heuveline's model for future work in the area. We feel that this model has the potential to be a useful tool for demographers interested in studying and projecting populations experiencing HIV/AIDS epidemics. Heuveline (2003) extended the classic cohort-component method to include additional states for HIV status, which could be developed even further to include separate states for those who are infected with HIV and who are also using antiretroviral therapies (ARTs). As the use of ARTs increases, the survival distribution of the infected population may change considerably, and Heuveline's multi-state CCMPP could be used to compare different intervention strategies involving (age-specific) changes in the use of ARTs. Bayesian melding could also be used to measure the uncertainty around different outcomes of interest.

While there is much to be gained from Heuveline's model, it should be pointed out that

as HIV epidemics are maturing, additional assumptions need to be made about the trend in HIV incidence. The results presented in this analysis assume a constant risk of infection over time, which may be unrealistic given evidence from certain populations (e.g. Mbulaiteye et al., 2002). In an analysis of the effect of HIV/AIDs on the fertility decline in Zimbabwe Terceira et al. (2003) provide an interesting discussion of the mechanisms and evidence for an effect of HIV prevalence on the fertility of uninfected women. They note that perceived risk of infection may lead to the adoption of contraceptives or abstinence to avoid infection (and simultaneously reduce fertility). It is reasonable to suspect that social networks serve as the conduit through which social learning or influence (and subsequent behavior change) occurs, particularly considering past evidence on the links between social networks and contraceptive use (Behrman et al., 2002; Kohler et al., 2001). In networks with high prevalence, members may be more likely to learn about network partners or distant/weak network ties becoming infected, which may influence contraceptive use with the goal of preventing infection. Thus, as HIV prevalence increases it is reasonable to expect behavioral changes/responses that reduce HIV infection. This possibility suggests that more attention needs to be paid to how a realistic trend in HIV incidence can be incorporated into Heuveline's model, as well as how uncertainty in this trend relates to uncertainty in the model's projections.

FIGURES

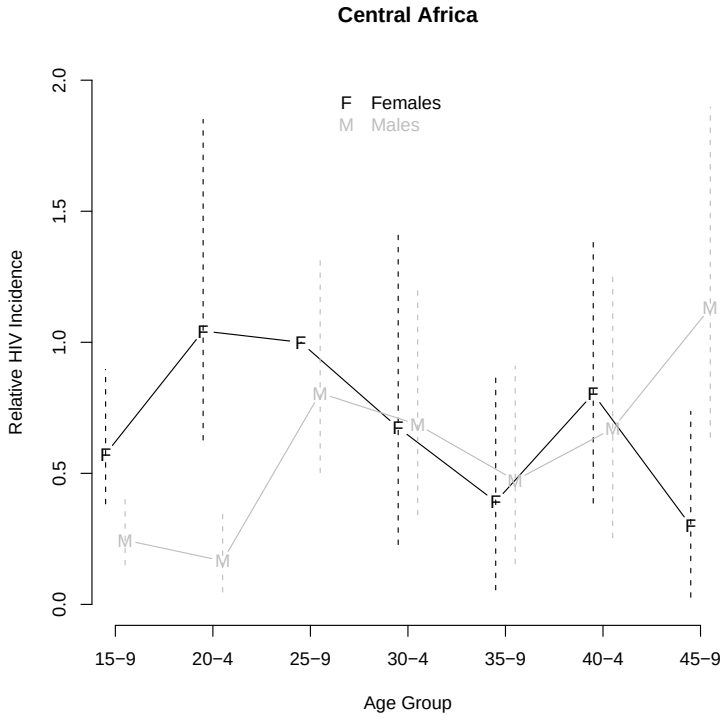

Figure 1: Posterior medians and 95% credible intervals for the relative HIV incidence ratios estimated for females (F - black) and males (M - gray) living in central Africa using DHS data. Females aged 25-9 serve as the reference group.

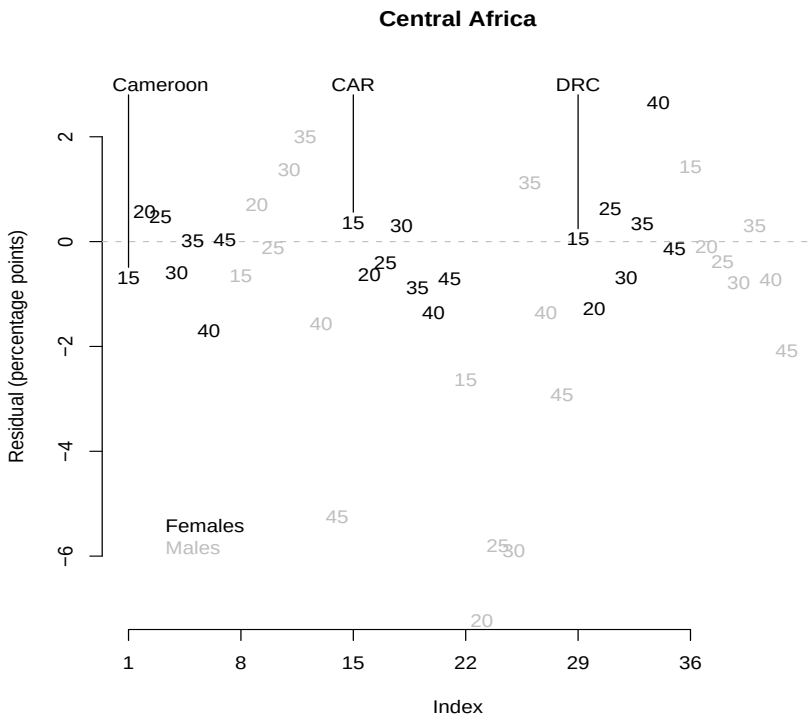

Figure 2: Residual plot of the observed level of HIV prevalence (in the DHS data) minus the projected value, obtained using CCMPP, for countries in central African. The numbers plotted indicate the lower bound of the five-year age group. Residuals for females (males) are plotted in black (grey).

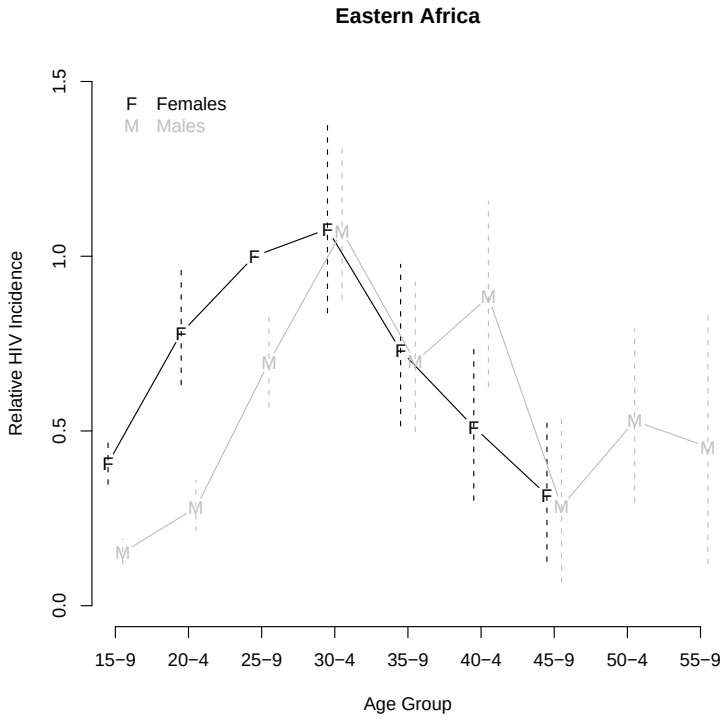

Figure 3: Posterior medians and 95% credible intervals for the relative HIV incidence ratios estimated for females (F - black) and males (M - gray) living in eastern Africa using DHS data. Women aged 25-9 serve as the reference group.

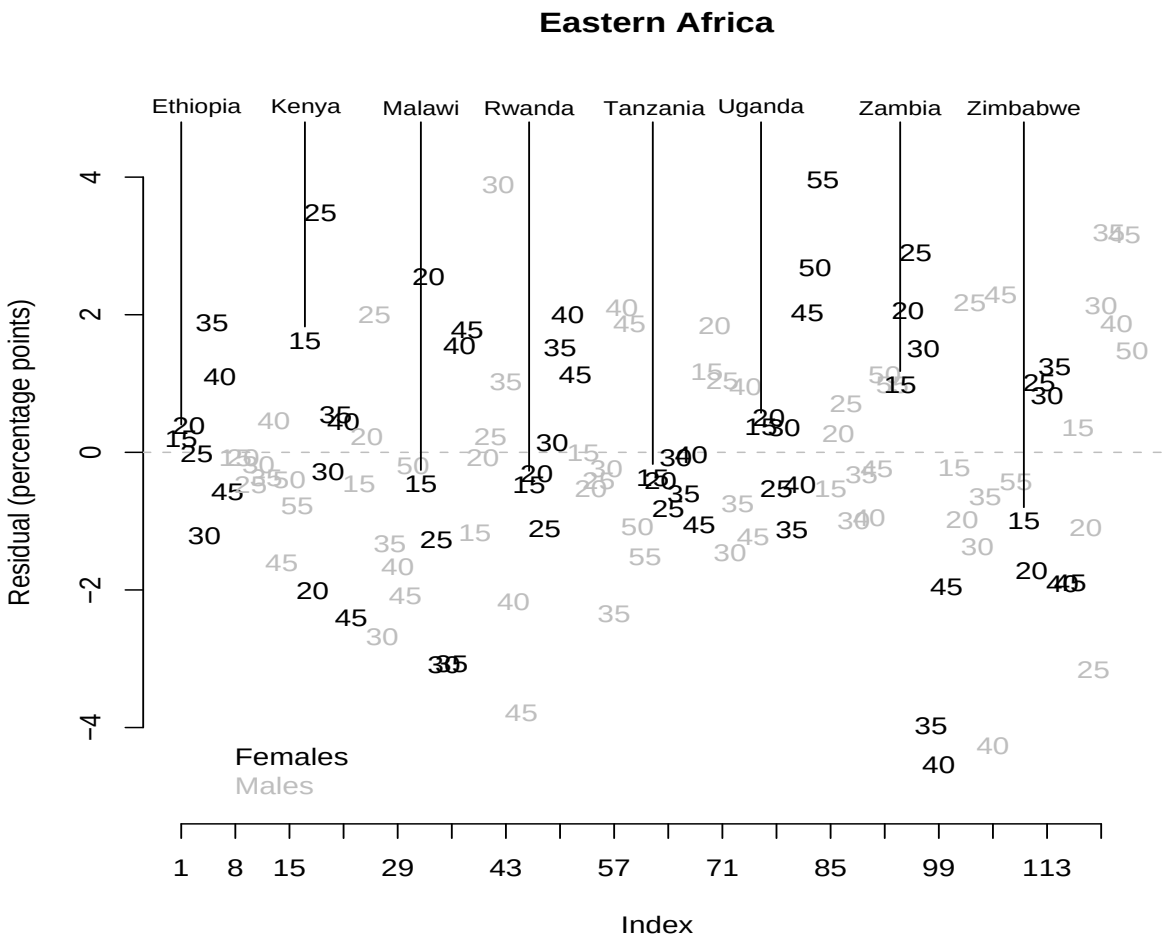

Figure 4: Residual plot of the observed level of HIV prevalence (in the DHS data) minus the projected value, obtained using CCMPP, for countries in eastern African. The numbers plotted indicate the lower bound of the five-year age group. Residuals for females (males) are plotted in black (grey).

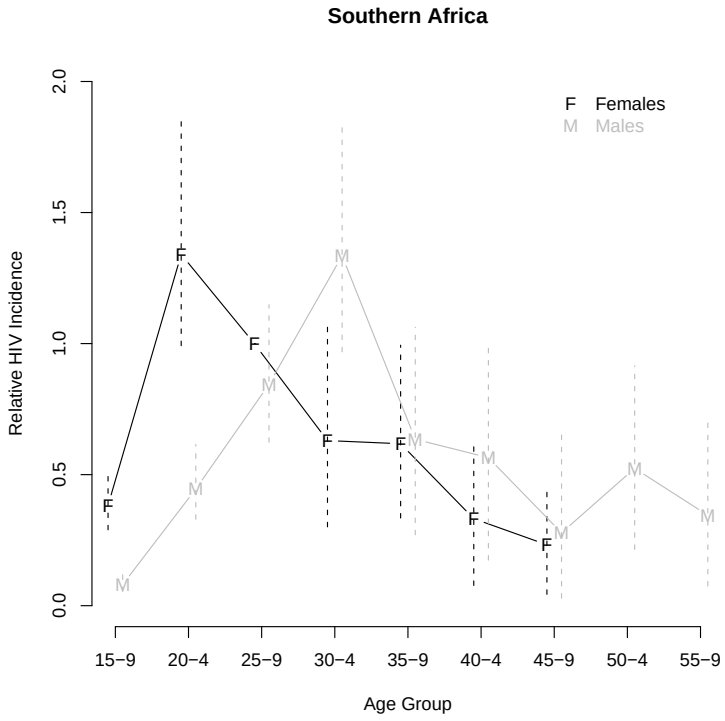

Figure 5: Posterior medians and 95% credible intervals for the relative HIV incidence ratios estimated for females (F - black) and males (M - gray) living in southern Africa using DHS data. Women aged 25-9 serve as the reference group.

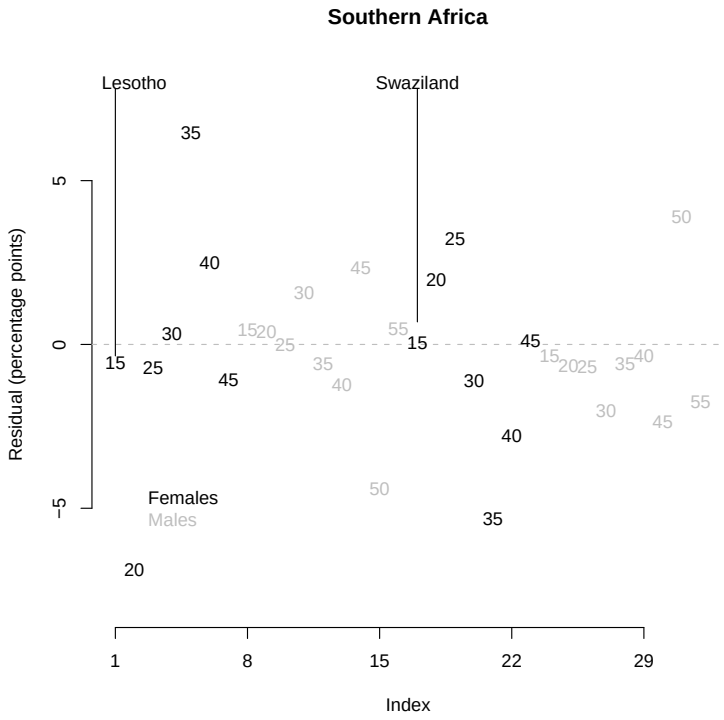

Figure 6: Residual plot of the observed level of HIV prevalence (in the DHS data) minus the projected value, obtained using CCMPP, for countries in southern African. The numbers plotted indicate the lower bound of the five-year age group. Residuals for females (males) are plotted in black (grey).

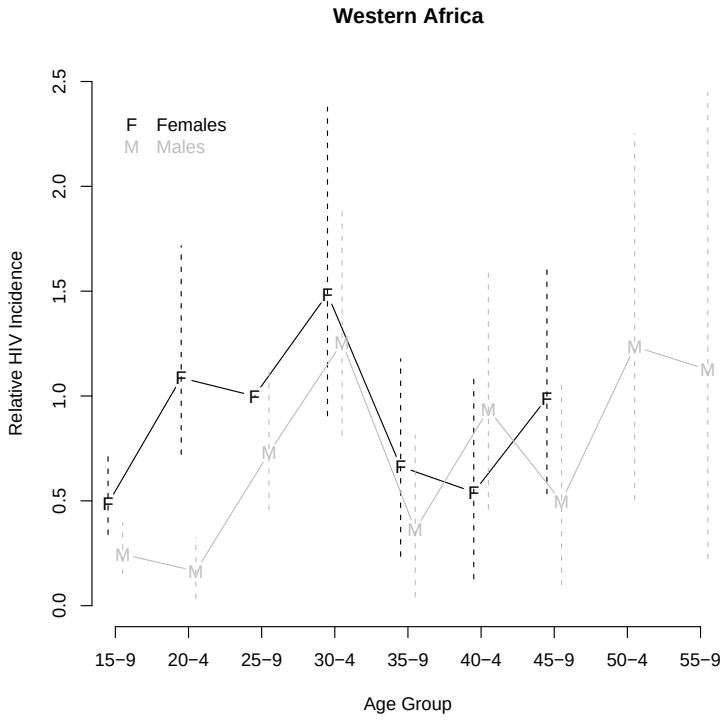

Figure 7: Posterior medians and 95% credible intervals for the relative HIV incidence ratios estimated for females (F - black) and males (M - gray) living in western Africa using DHS data. Women aged 25-9 serve as the reference group.

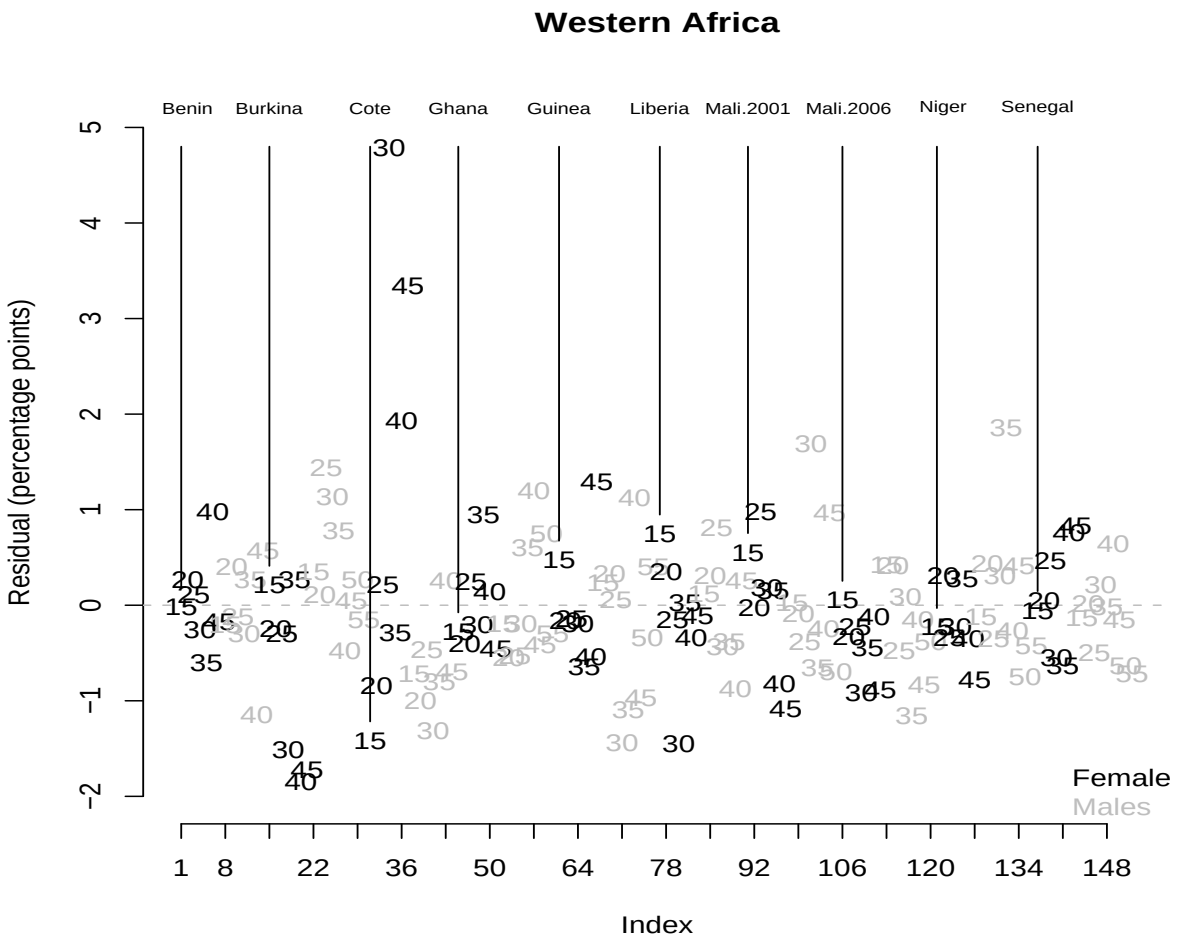

Figure 8: Residual plot of the observed level of HIV prevalence (in the DHS data) minus the projected value, obtained using CCMPP, for countries in western African. The numbers plotted indicate the lower bound of the five-year age group. Residuals for females (males) are plotted in black (grey).

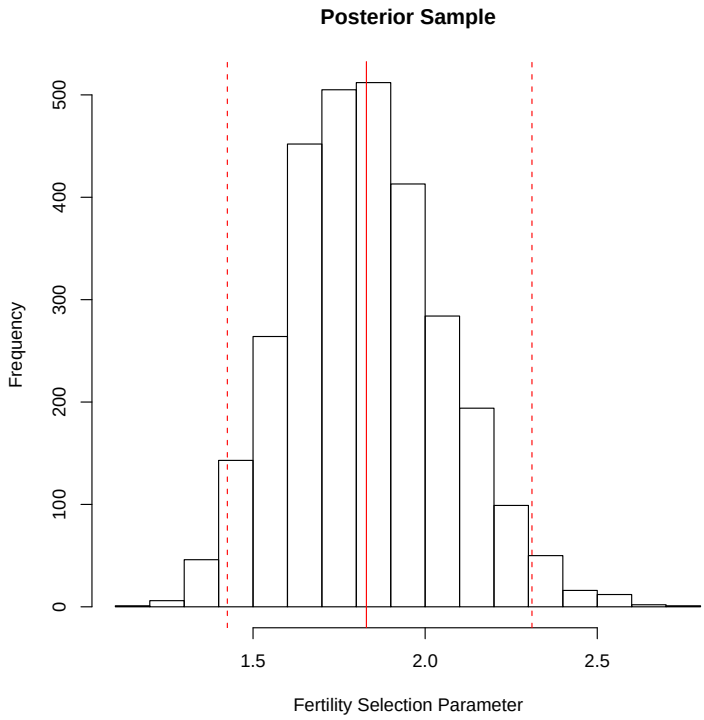

Figure 9: Histogram of the sample taken from the posterior distribution of the fertility selection parameter in Heuveline's multi-state CCMPP. The data consist of sources in East Africa (Heuveline, 2003; Thomas and Clark, 2008).

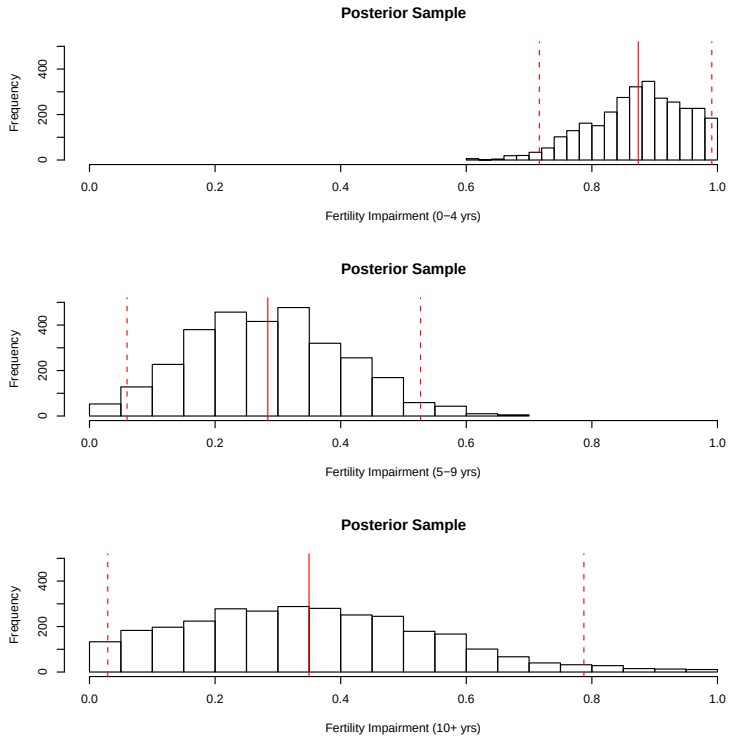

Figure 10: Histograms of the samples taken from the posterior distribution of the fertility impairment parameters, for women infected for 0-4 years, 5-9 years, and 10+ years in Heuveline's multi-state CCMPP. The data consist of sources in East Africa (Heuveline, 2003; Thomas and Clark, 2008).

TABLES

Table 1: Projected values and 95% credible intervals for the PAC in ASFR, the PAC in the TFR, and the age-specific prevalence for women from countries in central Africa. These projections were obtained using Heuveline's CCMPP model with parameters estimated using DHS data.

	Cameroon			**CAR**			**DRC**		
	HIV Prevalence			HIV Prevalence			HIV Prevalence		
Age Group	HIV+ 0-4	HIV+ 4 <	PAC	HIV+ 0-4	HIV+ 4 <	PAC	HIV+ 0-4	HIV+ 4 <	PAC
15-9	2.8	0.0	-0.3	3.2	0.0	-0.4	0.6	0.0	-0.1
	(2.2, 3.5)	(0.0, 0.0)	(-0.8, 0.0)	(2.5, 4.0)	(0.0, 0.0)	(-0.9, 0.0)	(0.5, 0.8)	(0.0, 0.0)	(-0.2, 0.0)
20-4	4.9	2.1	-2.1	5.6	2.4	-2.4	1.1	0.5	-0.5
	(3.8, 6.1)	(1.7, 2.6)	(-2.8, -1.5)	(4.4, 7.0)	(1.9, 3.1)	(-3.3, -1.7)	(0.8, 1.5)	(0.4, 0.6)	(-0.7, -0.3)
25-9	4.5	5.1	-4.1	5.2	5.8	-4.7	1.1	1.1	-0.9
	(3.0, 6.3)	(4.3, 5.9)	(-5.0, -3.2)	(3.4, 7.2)	(5.0, 6.9)	(-5.7, -3.7)	(0.7, 1.6)	(0.9, 1.4)	(-1.2, -0.7)
30-4	3.0	6.6	-4.9	3.5	7.6	-5.7	0.7	1.5	-1.1
	(1.3, 4.8)	(5.6, 7.7)	(-6.1, -3.5)	(1.5, 5.5)	(6.5, 8.9)	(-7.0, -4.1)	(0.3, 1.2)	(1.2, 1.9)	(-1.4, -0.8)
35-9	1.8	5.7	-4.1	2.1	6.6	-4.8	0.4	1.3	-0.9
	(0.3, 3.6)	(4.6, 6.8)	(-5.3, -2.6)	(0.3, 4.1)	(5.4, 7.9)	(-6.1, -3.0)	(0.1, 0.9)	(1.0, 1.6)	(-1.2, -0.6)
40-4	3.6	3.7	-3.0	4.2	4.3	-3.5	0.8	0.8	-0.7
	(1.9, 5.5)	(2.8, 4.9)	(-4.2, -1.7)	(2.2, 6.3)	(3.3, 5.6)	(-4.8, -2.0)	(0.4, 1.3)	(0.6, 1.1)	(-1.0, -0.4)
45-9	1.3	3.8	-2.8	1.6	4.5	-3.3	0.3	0.9	-0.6
	(0.1, 3.2)	(2.9, 4.9)	(-3.7, -2.0)	(0.1, 3.7)	(3.3, 5.7)	(-4.3, -2.3)	(0.0, 0.8)	(0.6, 1.1)	(-0.9, -0.4)
TFR			-3.2			-3.7			-0.7
			(-3.9, -2.5)			(-4.4, -2.9)			(-0.9, -0.5)

Table 2: Projected values and 95% credible intervals for the PAC in ASFR and the PAC in the TFR for women from countries in eastern Africa. These projections were obtained using Heuveline's CCMPP model with parameters estimated using DHS data.

	PAC in ASFRs and TFRs							
Age Group	Ethiopia	Kenya	Malawi	Rwanda	Tanzania	Uganda	Zambia	Zimbabwe
15-9	-0.1	-0.3	-0.5	-0.1	-0.3	-0.3	-0.7	-0.9
	(-0.1, 0.0)	(-0.7, 0.0)	(-1.2, 0.0)	(-0.3, 0.0)	(-0.7, 0.0)	(-0.6, 0.0)	(-1.6, -0.1)	(-2.0, -0.1)
20-4	-0.4	-1.7	-3.2	-0.8	-1.9	-1.7	-4.3	-5.5
	(-0.5, -0.3)	(-2.3, -1.2)	(-4.2, -2.3)	(-1.1, -0.6)	(-2.5, -1.4)	(-2.2, -1.2)	(-5.6, -3.1)	(-7.1, -4.0)
25-9	-0.8	-3.6	-6.5	-1.7	-3.9	-3.5	-8.8	-11.2
	(-1.0, -0.6)	(-4.4, -2.8)	(-7.9, -5.2)	(-2.1, -1.3)	(-4.7, -3.1)	(-4.3, -2.8)	(-10.6, -7.0)	(-13.2, -9.0)
30-4	-1.1	-5.2	-9.3	-2.4	-5.6	-5.1	-12.5	-15.9
	(-1.4, -0.9)	(-6.3, -4.0)	(-11.3, -7.2)	(-3.0, -1.9)	(-6.8, -4.4)	(-6.1, -4.0)	(-15.2, -9.7)	(-18.9, -12.2)
35-9	-1.2	-5.6	-10.2	-2.7	-6.1	-5.5	-13.7	-17.4
	(-1.6, -0.9)	(-6.9, -4.3)	(-12.3, -7.6)	(-3.3, -2.0)	(-7.4, -4.7)	(-6.6, -4.2)	(-16.7, -10.2)	(-21.0, -12.8)
40-4	-1.0	-4.7	-8.6	-2.2	-5.1	-4.6	-11.7	-14.9
	(-1.3, -0.7)	(-6.0, -3.2)	(-10.8, -5.8)	(-2.8, -1.5)	(-6.4, -3.5)	(-5.7, -3.2)	(-14.6, -7.7)	(-18.5, -9.9)
45-9	-0.7	-3.4	-6.2	-1.6	-3.7	-3.3	-8.5	-10.9
	(-1.0, -0.5)	(-4.4, -2.1)	(-8.0, -3.8)	(-2.0, -1.0)	(-4.7, -2.3)	(-4.2, -2.1)	(-10.9, -5.1)	(-14.0, -6.6)
TFR	-0.8	-3.4	-6.1	-1.4	-3.7	-3.3	-8.2	-10.6
	(-1.0, -0.6)	(-4.2, -2.7)	(-7.3, -4.8)	(-1.7, -1.1)	(-4.5, -3.0)	(-3.9, -2.6)	(-10.0, -6.5)	(-12.6, -8.4)

Table 3: Projected values and 95% credible intervals for the PAC in ASFR and the PAC in the TFR for women from countries in southern Africa. These projections were obtained using Heuveline's CCMPP model with parameters estimated using DHS data.

	PAC in ASFRs and TFRs	
Age Group	Lesotho	Swaziland
15-9	-1.0	-1.2
	(-2.4, -0.1)	(-2.8, -0.1)
20-4	-7.6	-8.9
	(-10.9, -5.0)	(-12.8, -6.0)
25-9	-19.0	-22.3
	(-22.2, -15.5)	(-26.0, -18.3)
30-4	-21.8	-25.6
	(-27.0, -14.7)	(-31.7, -16.9)
35-9	-19.4	-23.0
	(-25.1, -11.4)	(-29.8, -13.2)
40-4	-14.4	-17.2
	(-18.1, -9.2)	(-21.5, -10.8)
45-9	-9.6	-11.5
	(-12.6, -5.5)	(-15.1, -6.5)
TFR	-14.2	-18.0
	(-17.0, -11.2)	(-21.4, -14.0)

Table 4: Projected values and 95% credible intervals for the PAC in ASFR and the PAC in the TFR for women from countries in western Africa. These projections were obtained using Heuveline's CCMPP model with parameters estimated using DHS data.

	PAC in ASFRs and TFRs								
Age Group	Benin	Burkina Faso	Côte d'Ivoire	Ghana	Guinea	Liberia	Mali	Niger	Senegal
15-9	0.0	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	0.0	0.0
	(-0.1, 0.0)	(-0.2, 0.0)	(-0.5, 0.0)	(-0.2, 0.0)	(-0.2, 0.0)	(-0.2, 0.0)	(-0.2, 0.0)	(-0.1, 0.0)	(-0.1, 0.0)
20-4	-0.3	-0.5	-1.4	-0.6	-0.4	-0.4	-0.4	-0.2	-0.2
	(-0.5, -0.2)	(-0.8, -0.3)	(-2.0, -0.9)	(-0.9, -0.4)	(-0.6, -0.3)	(-0.6, -0.3)	(-0.6, -0.3)	(-0.3, -0.1)	(-0.3, -0.1)
25-9	-0.7	-1.2	-3.1	-1.3	-0.9	-0.9	-0.9	-0.4	-0.4
	(-0.9, -0.5)	(-1.5, -0.9)	(-3.7, -2.4)	(-1.7, -1.0)	(-1.1, -0.7)	(-1.2, -0.7)	(-1.2, -0.7)	(-0.5, -0.3)	(-0.6, -0.3)
30-4	-0.9	-1.5	-4.0	-1.7	-1.2	-1.2	-1.2	-0.5	-0.6
	(-1.2, -0.6)	(-2.0, -1.1)	(-5.1, -2.8)	(-2.2, -1.2)	(-1.5, -0.8)	(-1.6, -0.9)	(-1.6, -0.8)	(-0.7, -0.3)	(-0.8, -0.4)
35-9	-1.0	-1.7	-4.6	-2.0	-1.3	-1.4	-1.4	-0.6	-0.6
	(-1.4, -0.8)	(-2.2, -1.3)	(-5.7, -3.5)	(-2.5, -1.5)	(-1.7, -1.0)	(-1.8, -1.0)	(-1.7, -1.1)	(-0.8, -0.4)	(-0.9, -0.4)
40-4	-0.8	-1.3	-3.4	-1.4	-1.0	-1.0	-1.0	-0.4	-0.5
	(-1.1, -0.4)	(-1.8, -0.8)	(-4.5, -2.0)	(-1.9, -0.9)	(-1.4, -0.6)	(-1.4, -0.6)	(-1.4, -0.6)	(-0.6, -0.2)	(-0.7, -0.3)
45-9	-0.6	-1.0	-2.7	-1.1	-0.8	-0.8	-0.8	-0.3	-0.4
	(-0.9, -0.3)	(-1.4, -0.6)	(-3.7, -1.5)	(-1.6, -0.7)	(-1.1, -0.4)	(-1.1, -0.5)	(-1.1, -0.5)	(-0.5, -0.2)	(-0.6, -0.2)
TFR	-0.6	-1.1	-2.7	-1.3	-0.8	-0.8	-0.8	-0.3	-0.4
	(-0.8, -0.5)	(-1.4, -0.8)	(-3.3, -2.1)	(-1.6, -1.0)	(-1.0, -0.6)	(-1.0, -0.6)	(-1.0, -0.6)	(-0.5, -0.2)	(-0.5, -0.3)

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