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Indirect estimation of age-specific induced abortion rates in Sub-Saharan Africa

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Abstract

There is a lack of international comparisons of abortion levels and age-specific abortion rates. This study evaluates two methods of indirect estimation of abortion incidence by age group and applies them using Demographic and Health Surveys from Burkina Faso, Ethiopia, Nigeria and Rwanda. The revised residual method rearranges Bongaarts' proximate determinants of fertility equation leaving the index of abortion on the left using the revised Bongaarts (2015) method, which produces age-specific abortion rates. The 'Classification Method' groups unclassified pregnancy termination data into induced or spontaneous abortions using WHO's (1996) protocol. The revised residual method produced consistent age-specific abortion patterns, but absolute levels of abortion varied widely depending on how the other indices were calculated. The classification method failed to classify most terminations into either category. Moreover, terminations were likely underreported, as the ratio of terminations per 1000 pregnancies was low. This study shows that the methods of indirect measurement of abortion need to be context-specific. The next steps of this study include estimating bias in the residual method using simulations.

Introduction

According to estimations, around 35% of pregnancies in Africa are unintended. Around a half of such pregnancies end in an induced abortion (from now on: *abortion*). Millions of women are treated each year due to complications of unsafe abortion in developing countries (Sedgh, Singh, and Hussain 2014; Singh, Sedgh, and Hussain 2010; Singh and Maddow-Zimet 2016). Three in four abortions in Africa in 2010-14 were unsafe (Ganatra et al. 2017) and abortion remains a key contributor to maternal morbidity and mortality in the area. For instance, in 2003-09 an estimated 10% (N≈125,000) of maternal deaths in Sub-Saharan Africa (SSA) were due to unsafe abortion (Say et al. 2014). SSA was the only area in the world, where deaths attributable to unsafe abortion increased between 1990 and 2013 (Kassebaum et al. 2014). This was perhaps in part due to increased exposure: estimated abortion rate in SSA in 2010-14 increased to 31-35 abortions per 1000 women aged 15-49 from 28-32/1000 in 1990-94 (Sedgh et al. 2016). Abortion is either illegal or only allowed if woman's life is at risk in most countries in SSA. Despite its contribution to maternal mortality and morbidity, little is known about which socio-demographic groups in Sub-Saharan Africa have a higher likelihood of obtaining abortions.

Due to its stigmatised nature, political and social sensitivity abortion is understudied and often severely underreported in surveys. No method of abortion estimation is able in most contexts to provide complete reports, and the choice of method depends on the goal of the estimation; studying a population's abortion rate, socio-demographic determinants of abortion, or abortion trends over time demand different methods (Rossier 2003; Singh, Remez, and Tartaglione 2010). Due to the issues with data collection, there is a lack of international comparisons on the subject as well as studies producing age-specific abortion rates.

This study aims to develop and evaluate methods of estimation of abortion incidence in data-poor countries using existing datasets. Demographic and Health Surveys (DHSs) data were chosen, because these data are internationally comparable and frequently collected in SSA. Using such secondary data sources enables international comparisons of abortion trends and determinants. Such comparisons help evaluate whether the methods used are robust across contexts. The study also aims to estimate differences in the incidence of abortion by age.

This study first evaluates and compares two methods, which can be used to indirectly estimate abortion incidence: the residual and the classification methods. The residual method takes advantage of the proximate determinants of fertility framework (Bongaarts 1978; Davis and

Blake 1956) to estimate the incidence of abortion in a population (see Data and Methods section). While this method has been used before (Johnston and Hill 1996), it was based on the old Bongaarts' (1978) model. The revised Bongraats' (2015) method is used here, which (unlike the old version) produces age specific estimates. Its accuracy has improved markedly (Bongaarts 2015). Many scholars have suggested improvements to the Bongaarts method over the years (see e.g. Jurczynska, Kuang, and Smith 2016; Stover 1998). Many of these critiques were taken into account in the revised Bongaarts method, but whenever that was not the case, we tested whether making modifications to the model according to these suggestions improved the results.

The classification method takes advantage of routinely collected DHS pregnancy termination data, which does not differentiate between induced and spontaneous abortions. A version of WHO's (1996) protocol is applied to classify terminations into induced and spontaneous based on circumstances preceding the termination (see Magnani, Rutenberg, and McCann 1996).

This paper shows preliminary results for four countries (Burkina Faso, Ethiopia, Nigeria and Rwanda) on testing the performance of the two methods using DHS data on all women of fertile age (i.e. ages 15 to 45/49) by 5-year age groups and investigates sensitivities in the estimates produced using the revised residual method.

Data and methods

Four countries with recent DHS calendar data and Guttmacher Institute's abortion incidence estimates (see Bankole et al. 2013; Bankole et al. 2015; Basinga et al. 2012; Moore et al. 2016) collected within two years of the DHS were selected: Burkina Faso 2010, Ethiopia 2016, Nigeria 2013 and Rwanda 2010. The 5-year retrospective DHS calendar records monthly contraceptive use, reasons for discontinuation, pregnancy history, fertility preferences and intentions. In the absence of reliable government abortion statistics, Guttmacher's studies provide a point of reference for this study's results.

The revised residual method

The residual method (see Johnston and Hill 1996) rearranges Bongaarts' proximate determinants of fertility equation leaving the index of abortion on the left. The Bongaarts' equation estimates fertility reduction from the theoretical maximum (i.e. 'total fecundity', TF) due to sexual exposure, contraceptive use, abortion, and postpartum infecundability. The revised residual method assumes that any reduction in fertility not accounted for in the other three indices is due to induced abortion. This study uses the revised Bongraats' (2015) method as the basis for the residual estimation (eq. 1).

Bongaarts method (1a)	*Revised residual method (1b)*	
$f(a) = C_m(a) * C_c(a) * C_i(a) * C_a(a) * f_f(a)$	$C_a(a) = \frac{f(a)}{C_m(a) * C_c(a) * C_i(a) * f_f(a)}$	*(1)*

where the modified indices are: *f(a)* fertility rate, C_m sexual exposure; C_c contraception; C_i postpartum infecundability; C_a abortion index; and f_f total fecundity rate. All indices are age-specific, as indicated by *(a)*.

The indices $C_m(a), C_c(a), C_i(a)$ and $C_a(a)$ range from 0 (inhibits all fertility) to 1 (does not have any impact on fertility). The calculation of the indices is described in Table 1.

Table 1. Calculating revised Bongaarts indices (Bongaarts 2015, 545).

Index	**Formula**	**Notes**	**Eq.**
$C_m(a)$	$C_m(a) = m(a) + ex(a)$	, where *m(a)* = proportion in union and *ex(a)* = sexually active women* not in union.	*(2a)*
$C_c(a)$	$C_c(a) = 1 - r(a)\big(u(a) - o(a)\big)e(a)$	, where *u(a)* = contraceptive prevalence among exposed women; *o(a)* = contraceptive overlap with PPI; *e(a)* = contraceptive effectiveness; *r(a)* = fecundity adjustment.	*(2b)*
$C_i(a)$	$C_i(a) = \frac{20}{18.5 + i(a)}$	, where *i(a)* = average duration of PPI.	*(2c)*
$C_a(a)$	$C_a(a) = \frac{f(a)}{f(a) + \left(\frac{14}{18.5 + i(a)}\right) * ab(a)}$	, where *ab(a)* is a regional abortion rate as estimated by (Sedgh et al. 2012)**.	*(2d)*

Notes: PPI = postpartum infecundability. *Women who are not married or cohabiting are counted as sexually active, if they report sex within the last month, are using a contraceptive method, are pregnant or postpartum abstaining. ** In our study, the regional abortion rates were taken from (Sedgh et al. 2016) rather than (Sedgh et al. 2012).

The index of interest, that is, index of abortion $C_a(a)$, estimates the fertility reducing effect of abortion. It can be transformed to age-specific abortion rates and a total abortion rate (TAR), which is analogous to total fertility rate (TFR). TAR can be used to estimate the abortion rate per 1000 women of reproductive age. In the Bongaarts model, it is estimated using formula 2d in Table 1, which we also use in some of the evaluations of these models (see below for more information).

The advantages of using the revised Bongaarts method rather than the old Bongaarts method (see Bongaarts 1978) include its improved accuracy in correctly estimating the TFR in the population compared to the old method (Bongaarts 2015) and that it produces age-specific rates. The old method's limitations include possible bias in the other indices (Reinis 1992), which leads to bias in the residual estimate of $C_a(a)$. The new method has taken steps to reduce such bias. In addition, the old method assumes that abortion's effect on total fecundity (TF) is negligible. The estimated TF thus may include some fertility-reducing effect of abortion (Johnston and Hill 1996). However, as the revised residual method uses observed age-specific fertility rates (ASFRs) for index *f(a)*, any discrepancies between the observed and estimated ASFRs may still cause bias to the abortion estimate.

Evaluating the residual method

We modified the method according to some critiques of the Bongaarts method and evaluated whether that improved the accuracy of the residual model. To evaluate the accuracy, we first compared the resulting abortion rates to those estimated by the Guttmacher Institute (see Bankole et al. 2013; Bankole et al. 2015; Basinga et al. 2012; Moore et al. 2016). The evaluation of the accuracy of the abortion rate estimates was based on the Guttmacher Institute estimates, because no reliable national estimates of abortion exist in these countries.

Second we evaluated the accuracy of these different versions of the revised Bongaarts model in estimating TFR correctly, because the residual method is dependent in the model being able to estimate fertility rates correctly. We compared the estimated TFR from the Bongaarts model to the observed TFR based on DHS data to evaluate its accuracy. When evaluating the discrepancy between the estimated and the observed TFR, $C_a(a)$ was calculated according to Bongaarts' (2015) instructions (see Table 1, equation 2d).

Finally, we summed the absolute values of the differences between the estimated abortion rates and the Guttmacher abortion rates over all the four countries to compare which version of the method provides the smallest errors over all four contexts. We also conducted this calculation for the TFR accuracy evaluations.

We applied the following versions of the method: (1) using proximate determinants measured 27 months before the survey, (2) using proximate determinants measured at the time of survey and ASRFs measured over three years preceding the survey, (3) using proximate determinants measured at the time of survey and ASRFs measured over 12 months preceding the survey, (4) using regional estimates of contraceptive effectiveness *e(a)* (see Polis et al. 2016) rather than the general estimates provided by Bongaarts and Potter (1983), (5) changing the definition of sexually active women *ex(a)* to include all women who have ever had sex (see

Jurczynska, Kuang, and Smith 2016), and (6) using country specific estimates of the theoretical total fecundity $f_f(a)$ rather than the estimates proposed by Bongaarts (2015) (see Jurczynska, Kuang, and Smith 2016).

Finally, we will run simulations, which show how much the estimates of abortion rates change if there is error in the other indices. This will give us an idea of how much bias and uncertainty there might be in the abortion estimates, if the other indices are specified incorrectly. In addition, the simulations show if the model is more robust for errors in some indices than in others.

Model 1: lagged measurement of proximate determinants. Bongaarts (2015) suggests that all proximate determinants should be measured 27 months before the survey, because the DHS usually reports TFRs based on data up to 36 months preceding the survey. Thus, the proximate determinants that affect fertility over the three year period, have on average taken place 18+9 = 27 months before the survey (18 being the mid-point of 36 months, and 9 months being the time of gestation) (see also Jurczynska, Kuang, and Smith 2016). However, Bongaarts (2015) does not specify, how exactly the proximate determinants should be calculated given that DHS does not collect retrospective data for some of the relevant variables.

We used DHS calendar data to estimate contraceptive method mix 27 months before the survey. As union histories are not collected by DHS, we assumed that women who were in union at the time of the survey and whose first union had started at least 27 months before the survey, were in a union 27 months before the survey. As there is no information about women's sexual activity in the past, we assumed those reporting having had sex within the last 4 weeks preceding the survey to have also been sexually active 27 months ago. Postpartum infecundability was calculated using the mean duration of breastfeeding and postpartum abstinence after having children aged up to 36 months at the time of the survey. The observed ASRFs we use to replace index *f(a)* in the revised residual method, were calculated based on data up to 36 months preceding the survey.

Model 2: current status proximate determinants and three-year ASFRs. Given the issues with calculating the lagged proximate determinants, we next used the approach of the old Bongaarts model, where the proximate determinants are based on current status measures, while the observed ASFRs were calculated based on data up to 36 months preceding the survey.

Model 3: current status proximate determinants and one-year ASFRs. In order to decrease the discrepancy between the time of measuring ASRFs and the proximate determinants that resulted in these observed fertility rates, we next calculated the indices based on current status measures of proximate determinants, while the observed ASRFs were calculated based on data from up to only 12 months preceding the survey.

Model 4: region-specific contraceptive effectiveness. Model 4 uses region-specific estimates of contraceptive effectiveness *e(a)* for East and West Africa calculated based on the failure rates for each method in each area (Polis et al. 2016). Where region-specific estimates were not available (i.e. when other method than pill, IUD, implant, injectable, condom, withdrawal or the rhythm method was used), effectiveness estimates from Bongaarts and Potter (1983) were used.

Model 5: different definition of sexually active women. In the revised Bongaarts method, women who are not in a union, but who are pregnant, contracepting, postpartum abstaining or report having had sex within the last month, are counted as sexually active and hence at a risk of pregnancy ('exposed women'). Jurczynska and colleagues (2016) used a broader definition, where all women who had ever had sex, were counted as 'exposed'. We tested, whether using Jurczynska and colleagues' (2016) definition improved the accuracy of the method.

Model 6: country-specific estimate of total fecundity. Jurczynska and colleagues (2016) found that the accuracy of the old Bongaarts method in Sub-Saharan African context improved markedly, when total fecundity was estimated using DHS data from each county rather than using the theoretical value of 15.3 (see e.g. Bongaarts 1978).

We estimated country specific values for the age specific total fecundity $f_f(a)$, using the four most recent DHS surveys for each country and averaging the value over the years. The index can be calculated from Bongaarts model by moving $f_f(a)$ to the right hand side of the equation and using observed values for the other indices (Bongaarts 2015).

$$f_f(a) = \frac{f(a)}{C_m(a) * C_c(a) * C_i(a) * C_a(a)} \quad (3)$$

In these analyses, the index of abortion was calculated using equation 2d in table 1. The regional abortion rates for East and West Africa were taken from Sedgh and colleagues (2016) and the rates from the years closest to each DHS were used.

Sensitivity Analysis

To provide intuition about the effect of measurement error and bias in the indexes used to construct the estimates of age specific abortion rates, we conducted a local sensitivity analysis. This uses the partial derivative of estimates with respect to each of the components of the proximate determinants of fertility to examine the effects of small changes in these values on abortion rates.

The expression for the $C_a(a)$ given in Eq. 1b can be re-arranged to give an expression for the age-specific abortion rate $ab(a)$ (Eq.2d).

$$
\begin{aligned}
ab(a) &= \frac{f_f(a)C_m(a)C_c(a)C_i(a)}{b(a)} - \frac{f(a)}{b(a)} \\
ab(a) &= \frac{20}{14} f_f(a)C_m(a)C_c(a) - \frac{f(a)}{b(a)} \\
b(a) &= \frac{14}{18 + i(a)}
\end{aligned}
$$

The equation for $ab(a)$ can be interpreted as describing abortion rates as the difference between the fertility rate that would exist without abortion (first term on the right hand side) and the observed fertility rate (second term), both corrected by factor $b(a)$ to account for the differing length of infecundability caused by a live birth versus an abortion.

Taking partial derivatives with respect to the measured indices, we have:

$$
\begin{aligned}
\frac{\partial ab(a)}{\partial f_f(a)} &= \frac{20}{14} C_m(a)C_c(a) \\
\frac{\partial ab(a)}{\partial C_m(a)} &= \frac{20}{14} f_f(a)C_c(a) \\
\frac{\partial ab(a)}{\partial C_c(a)} &= \frac{20}{14} f_f(a)C_m(a) \\
\frac{\partial ab(a)}{\partial f(a)} &= -\frac{1}{b} \\
\frac{\partial ab(a)}{\partial b} &= \frac{f(a)}{b^2}
\end{aligned}
$$

Converting these to elasticities provides the percentage change in abortion rates induced by a percentage point change in one of the variables used in estimation.

$$\frac{f_f(a)}{ab(a)}\frac{\partial ab(a)}{\partial f_f(a)} = \frac{20\ C_m(a)C_c(a)f_f(a)}{14\ ab(a)}$$
$$\frac{C_m(a)}{ab(a)}\frac{\partial ab(a)}{\partial C_m(a)} = \frac{20\ C_m(a)C_c(a)f_f(a)}{14\ ab(a)}$$
$$\frac{C_c(a)}{ab(a)}\frac{\partial ab(a)}{\partial C_c(a)} = \frac{20\ C_m(a)C_c(a)f_f(a)}{14\ ab(a)}$$
$$\frac{f(a)}{ab(a)}\frac{\partial ab(a)}{\partial f(a)} = -\frac{f(a)}{b\ ab(a)}$$
$$\frac{b}{ab(a)}\frac{\partial ab(a)}{\partial b} = \frac{f(a)}{b\ ab(a)}$$

As a consequence of the nature of Bongaarts' indices, which by construction are scaling factors, the elasticities of the first three elements are identical. The last two elasticities differ in sign but have the same magnitude.

The elasticities set out above reveal the relative sensitivities of abortion estimates to small changes in the proximate determinates of fertility. To aid interpretation, it is necessary to evaluate them at a set of representative age-specific schedules for abortion, age-specific fertility, sexual exposure, and total fecundity. The forms used for these schedules are set out below, and are designed to be relevant for country contexts similar to the contexts of our study countries. Single year of age schedules are used in order to more fully examine the age-specificity of sensitivity.

Natural fertility. For 'natural' fertility f_f, Bongaart's estimates are used directly, and smoothed using locally weighted scatterplot smoothing (LOESS) to provide single year of age estimates.

Age specific fertility rates. The schedule of age specific fertility rates was generated using a Hadwiger model (Hadwiger 1940) with TFR 3.5 and mean age of childbearing 26.

Sexual exposure. A logistic function is used to represent the shape of the C_m index over age. The mean age of first sexual exposure is assumed to be 19.

Post-partum infecundability. The number of additional months of infecundability added through breast-feeding, *i(a)* was chosen to be constant over the age range, and equal to 9, in line with the discussion in Bongaarts' (2015) work.

Abortion. In line with Sedgh et al. (2012), abortion schedules are assumed to take an inverted U-shape over the age-range, with the highest rates occurring for ages 20-29. A Weibull distribution is used to model this shape, although this choice is somewhat arbitrary. A Total Abortion Rate of 1 is assumed.

Contraception. In order to provide a complete set of schedules consistent with Bongaarts' formalism, the final element must necessarily be a deterministic function of the others. The contraception index is therefore calculated as:

$$C_c(a) = \frac{ab(a) + f(a)/b}{\frac{20}{14} f_f(a) C_m(a)}$$

Simulations

A better understanding of the behaviour of estimated influence of measured variables can be gained through Monte Carlo simulation experiments that estimate the effect of bias and variability in each input at a range of plausible index values. This will also allow the examination of the effect of the underlying measured variables used in constructing C_m, C_c and b, such as contraceptive effectiveness and use.

The classification method

The classification method classifies self-reported pregnancy terminations into spontaneous and induced abortions using a version of WHO's (1996) protocol (Magnani, Rutenberg, and McCann 1996). Terminations are assumed to have been induced, if the pregnancy occurred after a contraceptive failure, after an unwanted birth, to unmarried women aged under 25 years, or exceeded the desired number of children they ideally wanted to have. Terminations in the third trimester, after contraceptive discontinuation in order to conceive, or to married women with 0-1 children are assumed to have been spontaneous. The method is particularly suited for estimating the number of abortions per 1000 pregnancies (i.e. the abortion ratio).

We applied the classification method to DHS calendar data on pregnancy terminations. These data do not differentiate between induced and spontaneous abortions. The method requires taking into account woman's marital status at the time of the pregnancy, but time varying data on marriage was not available. Hence, we classified women as married, if the age in which they had started their first marriage/cohabitation was younger than the age in which the termination of interest occurred and if they reported being married/cohabiting at the time of interview. This may misclassify some women, whose unions have recently dissolved, but who were in a union at the time of pregnancy of interest. All terminations were included in the analyses even if some of them happened to the same woman.

Results

Revised residual method

First, Models 1-3 were compared for their accuracy in predicting abortion rates for women in fertile age when compared to the Guttmacher estimates and correctly estimating TFR (Table 2). In Model 1, we calculated $C_c(a)$, $C_i(a)$ and $C_m(a)$ as described in Bongaarts (2015). That is, the proximate determinants were calculated with a 27 month delay and ASFRs based on data up to 36 months before the survey. In Model 2, current status measures were used to calculate the proximate determinants. Model 3 proximate determinants were based on current status, but ASFRs were based on data up to 12 months before the survey to ensure the gap between measuring TFR and proximate determinants is as small as possible.

Table 2. Evaluation of the different versions of the revised residual method.

	Model	Difference to GI abortion rate	TFRe-TFRo	Age group	Country specific $f_f(a)$	Difference to Bongaarts (2015) $f_f(a)$
Burkina Faso				*15-19*	614	-65
2010	*Model 1*	58.2	0.63	*20-24*	619	-12
	Model 2	3.1	0.01	*25-29*	610	22
	Model 3	-4.6	-0.09	*30-34*	549	35
	Model 4	37.2	0.45	*35-39*	491	111
	Model 5	17.6	0.19	*40-44*	270	78
	Model 6	35.3	0.37	*45-49*	86	26
Ethiopia				*15-19*	831	152
2016	*Model 1*	54.6	0.48	*20-24*	700	69
	Model 2	18.2	0.10	*25-29*	632	44
	Model 3	4.3	-0.09	*30-34*	583	69
	Model 4	32.8	0.26	*35-39*	461	81
	Model 5	52.9	0.49	*40-44*	241	49
	Model 6	59.9	0.49	*45-49*	80	20
Nigeria				*15-19*	663	-16
2013	*Model 1*	88.9	1.09	*20-24*	629	-2
	Model 2	24.4	0.40	*25-29*	616	28
	Model 3	7.6	0.16	*30-34*	515	1
	Model 4	48.9	0.73	*35-39*	383	3
	Model 5	45.9	0.69	*40-44*	237	45
	Model 6	32.1	0.44	*45-49*	148	88
Rwanda	*Model 1*	-11.2	-0.19	*15-19*	1508	829
2010	*Model 2*	-43.7	-0.59	*20-24*	804	173
	Model 3	-14.6	-0.21	*25-29*	632	44
	Model 4	17.6	0.17	*30-34*	608	94
	Model 5	62.6	0.65	*35-39*	509	129
	Model 6	80.6	0.84	*40-44*	349	157

Guttmacher Institute's abortion rate estimates for women in fertile age were 25 abortions per 1000 women of fertile age in Burkina Faso (Bankole et al. 2013), 22/1000 in Ethiopia (Moore et al. 2016), 33/1000 in Nigeria (Bankole et al. 2015) and 25/1000 in Rwanda (Basinga et al. 2013). The differences between Guttmacher abortion rates and the revised residual method abortion rates in absolute values summed over all four countries were 212.9, 89.4, and 31.4 for models 1, 2 and 3, respectively (not shown). The differences between estimated and observed TFRs in absolute values summed over all four countries were 2.4, 1.1, and 0.6 for models 1, 2 and 3, respectively (not shown). As model 3 performed the best in estimating both abortion rates and TFRs, it was used as the basis of further exploration of the model. That is, models 4-6 use current status data for proximate determinants and ASFRs measured up to 12 months before the survey. Table 3 shows the resulting indices of abortion $C_a(a)$ and age-specific abortion rates (ASARs) to all countries and across models.

Table 3, Model 4 shows the results of the revised residual method, where contraceptive effectiveness is calculated using region-specific values from Polis and colleagues (2016) rather than the overall estimates from Bongaarts and Potter (1983). Model 5 is the same as model 3, except that those who are counted as being exposed to a pregnancy include all women who report ever having had sex. Model 6 is the same as model 3, except that the theoretical total fecundity values were calculated for each country using the mean $f_f(a)$s calculated from four most recent DHSs for each country. These country specific values and their differences to the values suggested by Bongaarts (2015) are shown in the two last columns in Table 2. The values make it clear that there is considerable country-specific variation in the age-specific total fecundity estimates. For instance, the values for age group 20-24 range from 619 to 804 rather than being close to 627 as estimated in Bongaarts (2015). The differences in the youngest and oldest age groups are even larger.

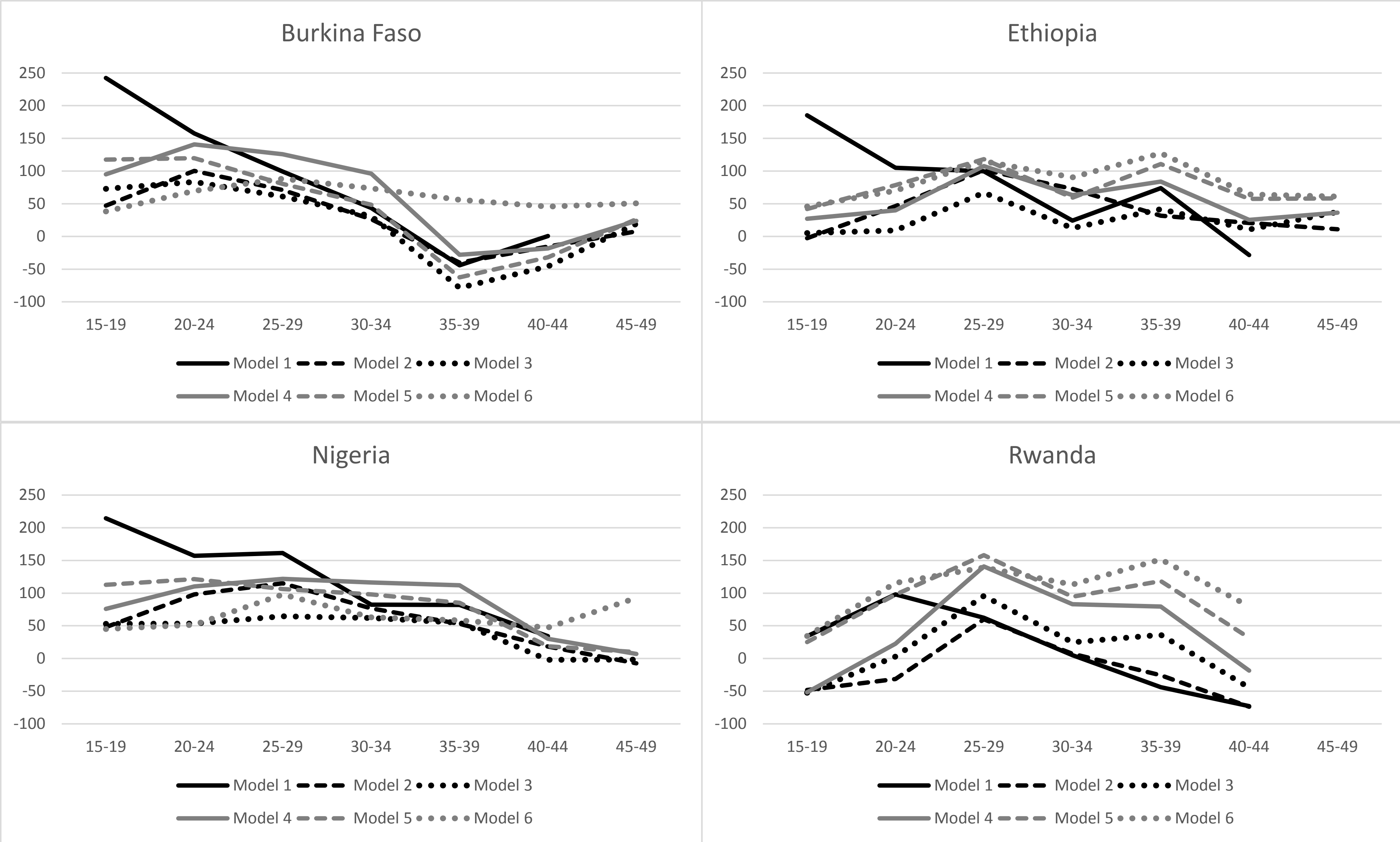
The differences between the Guttmacher Institute's abortion rates and the revised residual method abortion rates in absolute values summed over all four countries were 136.4, 178.9, and 207.9 for models 4, 5 and 6, respectively (not shown). The differences between estimated and observed TFRs in absolute values summed over all four countries were 1.6, 2.0, and 2.2 for models 4, 5 and 6, respectively (not shown). Hence, the models did not provide improvements to model 3, apart from model 6 not producing any negative age-specific abortion rate (ASAR) estimates (Table 3).

The results show that even small changes in how the Bongaarts model is specified has big implications on the resulting abortion rate estimates. The estimated abortion rates per women age 15-49 (15-45 in Rwanda) ranged from 20 to 83/1000 in Burkina Faso, 26 to 82/1000 in Ethiopia, 41 to 122/1000 in Nigeria, and -19 to 106/1000 in Rwanda (Table 3).

Table 3. Abortion indices ($C_a(a)$, residual method), age-specific abortion rates (ASAR) and overall abortion rate by country.

Model #		Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Features		**27 month delay in PDs**		**Current status (CS) with 3 year ASFRs**		**CS with 1 year ASFRs**		**CS with 1 year tfr and GI cp effectiveness**		**CS with 1 yr tfr and exposed woman = ever sex**		**CS with 1 yr tfr and country specific ffa**	
	Age	$C_a(a)$	*ASAR*	$C_a(a)$	*ASAR*	$C_a(a)$	*ASAR*	$C_a(a)$	*ASAR*	$C_a(a)$	*ASAR*	$C_a(a)$	*ASAR*
Burkina Faso 2010	*15-19*	0.592	242	0.869	47	0.798	73	0.751	95	0.710	117	0.882	38
	20-24	0.801	158	0.863	100	0.886	83	0.821	141	0.844	120	0.903	70
	25-29	0.872	99	0.902	71	0.916	61	0.841	126	0.892	80	0.883	88
	30-34	0.933	44	0.958	26	0.951	31	0.861	96	0.925	48	0.890	74
	35-39	1.095	-44	1.087	-40	1.171	-79	1.055	-28	1.131	-63	0.906	56
	40-44	0.998	1	1.069	-16	1.203	-46	1.073	-18	1.134	-32	0.856	46
	45-49			0.894	8	0.739	19	0.692	24	0.671	26	0.516	51
Abortion rate 15-49			83		28		20		62		43		60
Ethiopia 2016	*15-19*	0.544	185	1.015	-3	0.972	5	0.867	27	0.808	42	0.794	46
	20-24	0.826	105	0.916	47	0.984	9	0.932	40	0.874	79	0.887	70
	25-29	0.850	100	0.843	102	0.896	67	0.843	108	0.830	118	0.834	115
	30-34	0.955	24	0.874	73	0.978	13	0.899	63	0.905	59	0.862	90
	35-39	0.831	74	0.921	32	0.896	42	0.811	84	0.765	111	0.739	127
	40-44	1.163	-28	0.902	20	0.949	11	0.887	25	0.775	58	0.756	64
	45-49			0.843	11	0.468	37	0.475	36	0.362	58	0.351	61
Abortion rate 15-49			77		40		26		55		75		82
Nigeria 2013	*15-19*	0.599	214	0.859	48	0.844	53	0.791	76	0.718	113	0.864	45
	20-24	0.777	157	0.848	98	0.917	53	0.843	110	0.830	121	0.920	51
	25-29	0.784	161	0.835	115	0.908	65	0.839	122	0.856	106	0.866	98
	30-34	0.867	82	0.876	77	0.900	62	0.827	116	0.850	98	0.898	63
	35-39	0.826	82	0.878	53	0.874	55	0.772	112	0.817	85	0.867	58
	40-44	0.849	34	0.912	18	1.010	-2	0.876	30	0.919	19	0.818	47
	45-49			1.115	-7	1.026	-2	0.904	7	0.872	10	0.416	93
Abortion rate 15-49			122		57		41		82		79		65
Rwanda 2010	*15-19*	0.782	34	1.679	-48	1.737	-52	1.722	-52	0.831	25	0.782	34
	20-24	0.815	98	1.076	-31	0.993	3	0.948	23	0.807	98	0.779	116
	25-29	0.894	62	0.896	60	0.835	96	0.774	141	0.753	158	0.776	139
	30-34	0.990	5	0.985	7	0.948	25	0.846	83	0.829	94	0.802	113
	35-39	1.137	-44	1.076	-26	0.893	36	0.792	80	0.719	119	0.667	152
	40-44	1.452	-73	1.484	-74	1.294	-45	1.103	-18	0.862	32	0.712	80
Abortion rate 15-45			14		-19		10		43		88		106

Figure 1. Age-specific abortion rates based on models 1-6 by country.

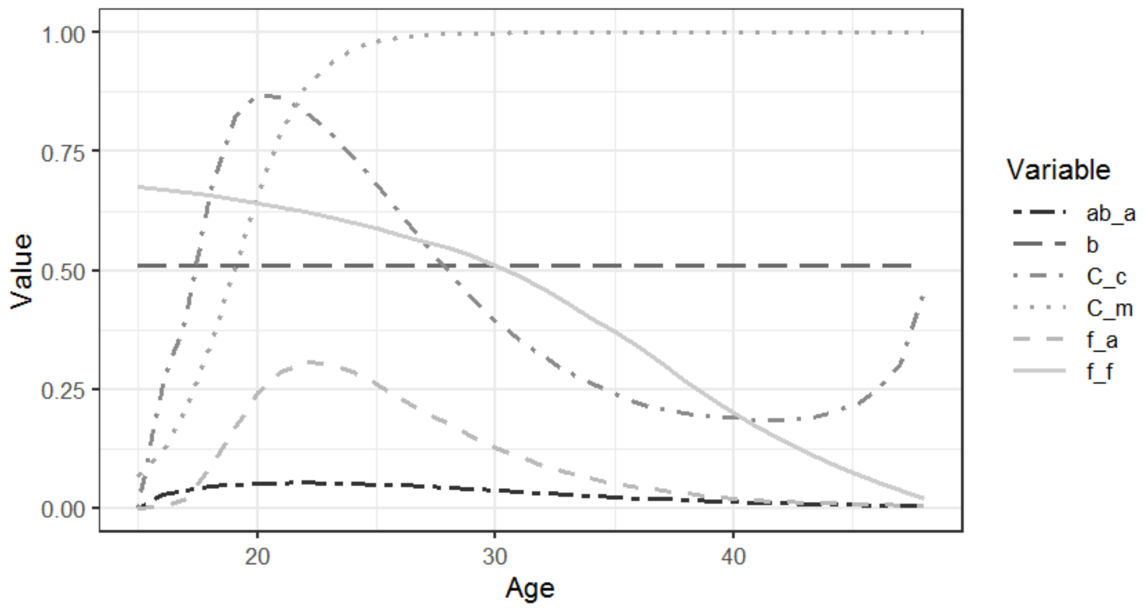


The age specific abortion rates, while different in their absolute values, were similar in shape across almost all models within each country (Figure 1). In Burkina Faso, the abortion rates were the highest among women in their 20s and early 30s, but there was a sharp decline after age 35. In Ethiopia and Rwanda, abortion rates peaked among women in their late 20s and late 30s, but are lower before, in between and after. In Nigeria abortion rates were high quite consistently from age 15 until age 39, but declined for women in their 40s.

Exploring bias and uncertainty in the revised residual method using sensitivity analyses

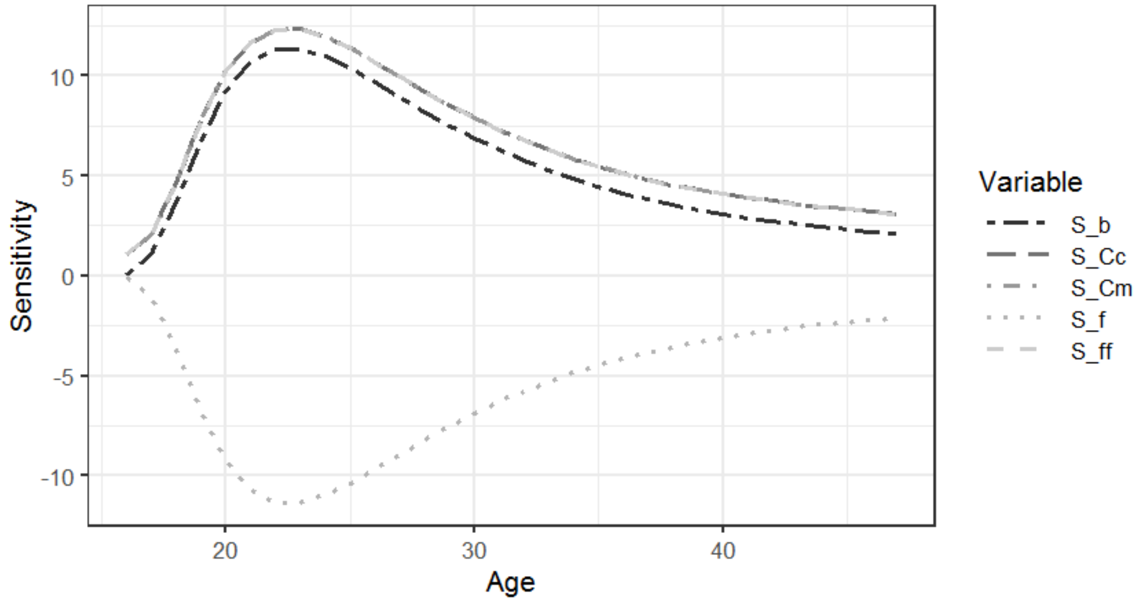
The local sensitivity analysis reveals the relative sensitivities of abortion estimates to small changes in the proximate determinates of fertility. Figure 2 shows the assumed schedules of the Bongaarts' indices in the sensitivity analyses.

Figure 2. Age-specific values of the indices used in the sensitivity analyses.



Evaluating the elasticities at these representative rates provides us with an idea of the potential size of the error in abortion estimates induced by mis-measurements of the other variables (Figure 3).

Figure 3. Age-specific percentage changes in the abortion rates when the variable of interest increases by 1%-point.



Notes: The sensitivities of f_f, C_m and C_c are the same, so the three lines lie on top of each other.

Figure 3 shows that a 1%-point increase in total fecundity (f_f), sexual exposure (C_m) and the index of contraception (C_c) lead to an inflation of the age-specific abortion rates up to 12%. The problem is the worst for women in their early 20s. The pattern is very similar for the factor *b(a)*, which is needed to estimate the index of abortion (Bongaarts 2015). On the other hand, a 1%-point increase in age-specific fertility rates leads to decrease in estimated age-specific abortion rates of up to 12%. Again, the problem is the worst for women in their early 20s.

Once conducted, Monte-Carlo simulations will provide further indications of the most important sources of bias and variation in the estimation of abortion rates using the residual method. This will allow an identification of cases when these estimates must be treated with care.

Classification method

Table 4 shows the results of the classification method. The method fails to classify most reported terminations into either category (spontaneous or induced) leaving the majority of terminations into the category of ‘unclassified termination’. It is likely that all terminations were underreported in these data, because the ratio of all terminations per 1000 pregnancies was much lower than expected. For instance, Casterline (1989) suggested that 100-150 spontaneous abortions take place per every 1000 pregnancies, which is considerably more than the 51-72 terminations per 1000 pregnancies reported in these data (Table 4).

Table 4. Classification method results (overall and age-specific): number of terminations per 1000 pregnancies.

	Age	Weighted N pregnancies	Abortion ratio	Miscarriage ratio	Unclassified ratio	Termination ratio
Burkina Faso	*15-19*	2338	4.7	63.0	0.0	67.7
	20-24	4808	3.7	31.8	9.4	44.9
	25-29	4480	2.3	16.9	25.4	44.6
	30-34	3126	2.7	15.5	31.1	49.3
	35-39	2041	10.1	12.3	35.8	58.2
	40-44	822	13.6	16.7	66.3	96.6
	45-49	109	6.7	27.2	102.8	136.7
Total		17724	4.5	26.3	22.3	53.1
Ethiopia	*15-19*	1306	9.7	46.7	2.3	58.7
	20-24	3466	2.1	21.6	11.2	34.9
	25-29	3500	5.0	20.1	18.1	43.2
	30-34	2417	9.4	19.2	29.6	58.2
	35-39	1505	17.0	8.4	36.3	61.7
	40-44	530	30.1	27.0	34.9	92.0
	45-49	85	0.0	89.0	152.3	241.3
Total		12809	7.9	22.4	20.5	50.8
Nigeria	*15-19*	4660	15.2	55.5	1.2	71.9
	20-24	9253	15.0	31.2	11.1	57.3
	25-29	9591	5.9	28.4	28.4	62.7
	30-34	6854	7.3	23.4	41.4	72.1
	35-39	4226	11.8	26.3	59.9	98.0
	40-44	1664	16.6	25.3	67.9	109.8
	45-49	410	13.1	40.9	112.6	166.6
Total		36658	10.9	31.4	29.4	71.7
Rwanda	*15-19*	514	13.3	38.3	0.0	51.6
	20-24	2919	6.2	56.1	3.2	65.5
	25-29	3146	2.4	33.7	13.3	49.4
	30-34	2128	8.4	24.7	25.4	58.5
	35-39	1329	23.3	17.9	34.8	76.0
	40-44	766	78.8	22.8	43.1	144.7
Total		10802	13.1	35.5	17.1	65.7

Discussion

Revised residual method

Model 1 did not perform well according to our evaluations. This may be because the data on contraceptive use 27 months before the survey is not reliable due to recall issues, which may create problems with estimating the index of contraception $C_c(a)$. Also, data on relationship status and sexual activity were not available other than at the time of survey. Alternatively, we could have calculated the method mix by interpolating between the DHS survey of interest and the previous survey (see Jurczynska, Kuang, and Smith 2016). This is based on the assumption that contraceptive use patterns and the proportions of married and ‘exposed’ women change linearly between the two surveys. While the interpolation method relies on this heavy assumption, its strengths include avoiding recall issues and problems due to some of the relevant variables only being available as current status measures.

Model 2 also performed quite poorly, which is likely to be due to the time gap between the observed ASFRs (over last three years before the survey) and the current status measures of proximate determinants being too large. The four countries included in this study have rapidly changing family planning and fertility environments, which means that assuming the proximate determinants have stayed relatively constant for almost four years is not a reasonable assumption. Model 3 was able to solve some of these issues by only using the last 12 months before the survey to calculate ASFRs. According to our evaluations, it was the most accurate model.

Model 4 used regional estimates of contraceptive effectiveness for East and West Africa (Polis et al. 2016) to calculate the index of contraception $C_c(a)$. Across all the countries, the resulting indices of contraception were much closer to one than in Model 3 (not shown), indicating that according to these region-specific estimates of contraceptive failure rates, contraceptive effectiveness is lower in these countries than if estimated using the effectiveness figures recommended by Bongaarts (Bongaarts 2015; Bongaarts and Potter 1983). However, according to our evaluations, using the region-specific estimates decreased the accuracy of the model compared to Model 3.

The wider definition of who is an ‘exposed woman’ (index $ex(a)$) used in Model 5, that is including everyone who ever reported having sex, did not improve the accuracy of the model. While the definition provided by Bongaarts (see Table 1 notes) may exclude some sexually active women if they had not been active in the last four weeks, the other extreme tested here may include many women who only have sex sporadically and thus are not exposed to the risk of pregnancy often.

Model 6 was the only model that did not produce any negative ASARs, but nevertheless its accuracy was the worst out of all the models we conducted. The large differences in the age specific total fecundity estimates between the four countries indicate that there are factors not included in the Bongaarts framework that affect the fertility levels in these contexts (Jurczynska, Kuang, and Smith 2016). The reason this did not result in improved estimates of abortion or TFR remains to be uncovered. It may be that estimating the $f_f(a)$ indices using a rearranged Bongaarts equation (eq. 3) and then rearranging it again to estimate abortions (eq. 1b) created too much bias in our estimates.

There were some limitations in this section of the study. First, as the ‘true’ abortion rates are not known, it is difficult to evaluate the performance of the methods. However, our measures of accuracy in the abortion rate estimates agreed well with the estimates of the accuracy of measuring TFR, which indicates that the Guttmacher abortion rate estimates might provide a reasonable point of comparison for our study. Second, the residual method is sensitive to any biases in the other three indices than abortion, and the big differences in abortion rate estimates between Models 1-6 as well as the sensitivity analyses show that even small differences in how these indices are measured can result in large discrepancies in the abortion rate estimates.

Classification method

Previous research suggests the classification method performs well even though it cannot take into account the increased miscarriage risk of older women, or abortions due to birth spacing (Magnani, Rutenberg, and McCann 1996). However, the results for the four countries studied here are unsatisfactory. The proportion of unclassified terminations increases by age. This indicates that not being able to take into account the increased risk of miscarriage by age is an important issue with these data. The large proportion of unclassified terminations also suggests that the criteria used to classify the terminations are not suitable for this context. The contraceptive use patterns and reasons for discontinuation, fertility preferences, and marital status used to classify terminations as induced or spontaneous, may have not been suitable for these four country contexts. While the criteria can be modified to increase the performance of this method in this context, more research is needed into why women have abortions in these countries and who these women are before the classification method can be improved. The likely underreporting of all terminations also creates issues in using the classification method for estimating abortion trends.

Conclusions

This study shows that there is no ‘one size fits all’ approach for indirect measurement of abortion. While some methods work well in some context, they may be completely unsuitable in others.

While the revised residual method provides different absolute estimates of abortion rates depending on how the proximate determinants are calculated, the age-specific patterns they produce are quite consistent. The method may be more suitable in studying age-specific abortion patterns than it is in studying absolute levels of abortion. However, the estimation of the age-specific abortion rates comes with the caveat that the model sometimes produces negative abortion rates, particularly among the youngest and the oldest age groups, where pregnancies are less common.

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