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New evidence about effects of reproductive variables on child mortality in sub-Saharan Africa

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ABSTRACT

There is considerable uncertainty about how reproductive factors affect child mortality. Joint determinants are difficult to control adequately for, and the studies that have dealt with selection in the most advanced ways have given diverging results. According to very simple models estimated from DHS data from 28 countries in sub-Saharan Africa, mortality is highest for first-born children with a very young mother. Also some other groups of children with a young mother, or of high birth order, have high mortality. Net of such age and birth order differences, a short preceding birth interval is associated with high mortality. The pattern does not change much if a number of other observed characteristics are controlled for, but a different picture appears if time-invariant unobserved mother-level characteristics are taken into account in a multilevel-multiprocess model. According to the latter models, the mortality of a first child goes up as the mother's age increases above 24, and younger siblings are adversely affected by the later start of childbearing as this means that their mother will be older when they are born. Avoiding a short birth interval reduces the chance that the next child dies, but this effect is weaker than suggested by the simpler models, and younger siblings have a disadvantage because their mothers are older than they otherwise would be. The conclusion is different if it is taken into account that a higher maternal age goes hand in hand with a later calendar period, which may reduce mortality. Assuming that the recent general mortality decline continues, the advice to a woman would be to avoid a very early first birth and short birth intervals. In addition to being an advantage in the short term, there are no disadvantages for the children she may have later. It is also discussed whether a woman's next child will have lower mortality than her most recently born child. The statistical analysis is backed up by a simulation experiment.

Key Words: birth interval, birth order, child, DHS, infant, maternal age, mortality, multilevel-multiprocess models, sub-Saharan Africa, reproductive variables, simulation

JEL codes: C30, I10, J13

SHORT ABSTRACT

There is considerable uncertainty about how reproductive factors affect child mortality. Joint determinants are difficult to control adequately for, and earlier studies have given diverging results. In this study, multilevel-multiprocess models that control for time-invariant unobserved mother-level characteristics are estimated, using DHS data from 28 countries in sub-Saharan Africa. There are less adverse effects of early first birth and short birth interval according to these models than according to simpler models. The implications of the results are discussed, taking into account that a higher age at the next birth, possibly as a result of a longer birth interval, will make the mother older also at subsequent births, and that a higher age for the mother necessarily means that that the child will be born in a later calendar year. It is also discussed whether a woman's next child will have lower mortality than her most recently born child.

Background

A number of studies from developing countries have shown that children born soon after an older brother or sister have poorer health and higher chance of dying in infancy or childhood than children born after a longer birth interval (Hobcraft 1983; Rutstein 2005; Saha and van Soest 2013; Kozuki and Walker 2013). Also a short subsequent birth interval has been associated with poor child health (DaVanzo et al., 2008; Fotso et al., 2012). The evidence is more mixed when it comes to birth order and maternal ages. Special disadvantages for first-born children and, to lesser extent, children of high birth order have been reported in several studies (Davanzo et al. 2008; Ezeh et al., 2014; Kozuki et al., 2013a), but some authors using more advanced methods to deal with selection have concluded that there is no effect of birth order (Kozuki et al., 2013c; Bhalotra and van Soest, 2008) or even a favourable influence of higher birth order (reported, but not shown, by Kudamatsu, 2012). Furthermore, a very low age at birth has been associated with high mortality (Ezeh et. al, 2014; Finlay et al. 2011; Gibbs et al., 2012; Kozuki et al., 2013a), and some studies have shown a moderate increase in child mortality from age 35 or 40 (Ezeh et al. 2014; Kozuki et al 2013a), whereas other authors have observed an increase already from around age 25 or 30 (Finlay et al. 2011; Bhalotra and van Soest 2008) or a generally adverse effect of higher age (uncommented estimates in Saha and van Soest 2013). None of these reported patterns is theoretically implausible. As explained below, several counteracting mechanisms are probably involved and the balance could tip in either direction.

Family planning programmes have to a large extent been motivated by the idea that such relationships between reproductive factors and child health are causal. In particular, attempts to help people avoid short birth intervals have been an important ingredient of these programmes. Furthermore, knowledge about causal effects (rather than statistical associations) not only constitutes the ideal underpinning of family planning programmes and population policies; it is also what individuals need in their fertility decisions making, and it adds to our general insight into human physiology. For other purposes, identification of causal effects may not even be a goal. In particular, health personnel and health care planners may sometimes just be interested in knowing which groups of children that are most vulnerable, in order to steer resources in that direction. This calls for a simple description of differences, for a relevant period and the country (or within-country setting) in which these persons operate.

In many earlier investigations that have aimed (perhaps implicitly) to identify a causal effect, many good attempts have been made to control for individual and societal characteristics that affect both women's reproduction and her children's health and mortality. However, there will always be doubt about whether this has been done adequately. Besides, when assessing the importance of a reproductive variable, other reproductive variables must be controlled for, as they are closely linked to each other, and these controls have often been rather crude. The fact that the results have also been rather mixed – even those coming from the statistically most advanced investigations - adds to the motivation for further analysis based on good data and methods.

The aim of the present study is to shed new light on the relationship between three main reproductive factors (birth order, maternal age, length of preceding birth interval) and child mortality, using state-of-the-art methods and data from all (readily) available Demographic and Health Surveys (DHS) conducted in sub-Saharan Africa after 2010 – with a focus on the last 10 years before the surveys. The issue is particularly pressing in this region, where infant mortality was as high as 64 per 1000 on average in 2015, under-5-mortality was 83 per 1000, and the total fertility rate was 5.0 (PRB 2015). Earlier studies have shown that associations with reproductive factors differ between infant and child mortality, and that there may also be differences within the infant period (e.g. Davanzo et al., 2008), but for simplicity this is largely ignored.

The first step of the study is to describe the relationships between the reproductive variables and child mortality by means of a simple regression model with only a few control variables included. As mentioned, this could be helpful for some purposes. In the next step, a number of variables are added to this model, and finally multilevel-multiprocess models are estimated to control also for constant unobserved characteristic of the mother (and the household and the community in which she lives) that affect both fertility and child mortality.

Based on these model estimates, it is discussed how alternative reproductive "strategies" affect a mother's chance of losing her next child and later children, assuming persistent effects of the reproductive variables. It is then taken into account that a short birth interval not only itself may increase the chance that the next child dies. A short interval also means that the mother will be slightly younger when she gives birth to that child, which may have an additional impact; besides, she will be younger at subsequent births. Furthermore, it is taken into account that, if a woman has a child at a younger age, the birth will necessarily take place in an earlier calendar period (Barclay and Myrskylä, 2016). The latter is likely to have an effect as well, for example because of continued general improvements in nutrition, sanitation and health care.

Some of the models include the reproductive factors as separate variables, while others include a variable that combines maternal age and birth order. The latter is a convenient approach (although good alternatives exist) because some combinations of these two factors are impossible or highly unlikely, and because it is possible that effects of maternal age vary with birth order.

Data from the various African countries are pooled because introductory analysis showed that estimates from country-specific models have large standard errors and fluctuate wildly and without displaying any meaningful pattern. For many countries, the estimation procedure did not even converge. The downside of such an analysis is that it does not reflect the likely variation in effects between (and within) all these countries because of heterogeneity in policies and the social and physical environment to which families are exposed. Only one simple step will be taken to shed some light on this variation: some models will be estimated separately for the least and the most developed among the 28 countries.

Theoretical Issues

A brief review of social and physiological mechanisms

The mentioned reproductive factors have been thought to affect the child's health and survival through many different, and partly counteracting, mechanisms. For example, low maternal age may increase child mortality because of a particularly heavy nutritional burden during pregnancy (from feto-maternal competition), physiological immaturity (leading to preterm births or obstetric complications), and less health knowledge and fewer material resources among the parents (Chen 2007; Gibbs et al. 2012; Finlay et al. 2011). On the other hand, the chance of chromosomal or congenital abnormalities increases as a woman approaches the end of her reproductive period, and the chance that the she suffers from hypertension, diabetes or other chronic diseases – with likely implications for the child's health - increases with age throughout her reproductive period. The possibility of an adverse effect of higher maternal age because of deteriorating health has been referred to as the "weathering hypothesis" (Geronimus 1992). In support of that idea, Powers (2013) found that the mortality of black infants in the US went up with increasing maternal age, and that there was an upturn from the mid-20s among Mexican-origin children. Furthermore, Love (2010) reported that, among socially disadvantaged African-Americans (but not others in the US), the chance of having a child of low birth weight was 50% higher if the mother was older than 30 than if she was younger than 20. Similarly, Goisis and Sigle-Rushton (2014) observed that, among black first-born children in the UK, the chance of low birth weight doubled when the mother's age increased from around 25 to 40 (while the same pattern did not appear among disadvantaged white children).

It has been suggested that first-born children have particularly high mortality compared to the later-born because the mother's body is not adapted to pregnancy and childbirth, which increases the chance of complications during childbirth (Lee et al. 2011). Besides, it is thought that children of *high birth order* are disadvantaged because of nutritional stress experienced by mothers during previous pregnancies and lactation periods and reproductive injuries (Montgomery and Lloyd 1996). Also, there may be fewer parental resources available when there are several older siblings (especially if these siblings are not old enough to help the younger or contribute to the family income; Kravdal et al. 2013). Finally, having many siblings may increase the chance of disease transmission (although effects are not necessarily adverse as relatively weak infections at low age could confer immunity; Cardoso, 2004).

On the other hand, it is also possible that child mortality goes *down* with increasing birth order because mothers and fathers have accumulated more experience with childrearing. Such an effect of birth order could also arise if having many children on the whole, and in spite of the disadvantages just mentioned, affects the parents' health positively, so that they can care better for their children. However, while studies from rich countries suggest that having relatively many children may lead to a healthier life style and better health (Kravdal et al., 2012), there is no such evidence from poor settings. As mentioned, the idea of a protective effect of higher birth order was supported by Kudamatsu (2012), who carried out a within-mother analysis with control for maternal age and period dummies.

When it comes to the firmly documented excess mortality after short birth intervals, several explanations have been suggested: i) inadequate time to recover from the nutritional depletion caused by the previous pregnancy, ii) cervical insufficiency/incontinence due to inadequate time to regain the strength of the muscles in the reproductive tissue, iii) breastfeeding of the preceding child during a substantial part of the pregnancy, with consequences for the intra-uterine environment and later breastfeeding, iv) higher chance of disease transmission from the mother, who may have been weakened in connection with the preceding birth, or because there is at least one very young sibling, and v) less resources available from the parents because the previous as well as older siblings will tend to be younger than if the interval is longer (see elaboration in Conde-Agudelo et al., 2012).

Most of these arguments would suggest that mortality continues to fall as the birth interval increases, at least up to a certain length. However, it has also been suggested that mortality may go up again if the interval becomes very long. The idea is that the woman becomes primed for fetal growth during a pregnancy, which gives her advantages in later pregnancies, but that this benefit disappears if she waits long, so that her capacity in that respect is like that of a childless woman (Zhu 1999).

Effect modifiers

The impact of the reproductive factors probably depends on a number of individual, household and societal characteristics, including the socioeconomic resources of the family or in the country. However, there is much complexity involved and therefore hard to make predictions. To give just a few examples of possible interactions, it is a key aspect of the "weathering hypothesis" that relatively rich women do not experience as strong general health deterioration with increasing age as the less resourceful. Furthermore, the nutritional-depletion argument may be less relevant among those with a generally adequate food intake, and there could also be other reasons for sharper effects of short birth intervals among the least resourceful (Whitworth and Stephenson 2002). Yet, Conde-Agudelo et al. (2006) concluded in a review that we do not actually know much about whether effects of spacing differ between developed and developing countries. When it comes to birth order, one could argue that the dilution-of-resources argument should carry less weight among the richest, but it has also been pointed out that better access to various health promoting amenities may intensify the competition among siblings (Desai 1995; Gibson and Lawson 2011).

In societies with strong son preferences, also the child's sex - and even the sex composition of the siblings - may condition the effects of the reproductive variables (e.g. Makepeace and Pal 2008). For simplicity, and because son preferences in large parts of Africa are weaker than in South and East Asia, this issue is not addressed in this study.

Selection

Child mortality is influenced by a number of individual or household characteristics, such as the economic resources of the parents, their knowledge, their trust in modern health care, their general health, and the mother's autonomy. Similar socioeconomic characteristics at the aggregate level are also important, for example through the availability of health care and the quality of the sanitation systems, and the natural environment has an effect above and beyond that (e.g. by affecting possibilities for microbial growth and survival of disease vectors). All these factors also influence the need for children as labour and old-age security, the access to contraception, and other important determinants of fertility. Some of them are often measured in surveys, and some may at least be reasonably constant over time for a given individual or family, so that they are taken into account by the approach used in this study. Others are more problematic to control for (see further discussion below).

Data and Methods

DHS surveys

The analysis was based on all 28 Demographic and Health Surveys (DHS) conducted in sub-Saharan Africa after 2010 and available at the end of 2015: Benin 2011, Burkina Faso 2010, Burundi 2010, Cameroon 2011, Congo (Brazzaville) 2011, Cote d'Ivoire 2011, Democratic Republic of Congo 2013, Ethiopia 2011, Gabon 2012, Gambia 2013, Ghana 2014, Guinea 2012, Lesotho 2009/10, Liberia 2013, Malawi 2010, Mali 2012, Mozambique 2011, Namibia 2013, Niger 2012, Nigeria 2013, Rwanda 2010, Senegal 2010, Sierra Leone 2013,Tanzania 2010, Togo 2010, Uganda 2011, Zambia 2013, and Zimbabwe 2010.[1] For simplicity, women with at least one twin were left out, as in many earlier studies (Davanzo et al., 2008; Saha and van Soest, 2013).[2] The focus was on the mortality of children born less than 10 years before interview, as a compromise between analyzing a recent period and including many children.[3] As described below, broadening the study period gave similar results.

The DHS surveys include region-specific weights that should be used when calculating country-level descriptive statistics, while it is less obvious that they should be used in estimation of statistical models. In this analysis, weights were not included. Introductory estimation showed that inclusion of region-specific weighs, or weights that also took the country size into account (thus placing more emphasis on DHS observations from, for example, Nigeria), had very little impact on the estimates.

Multilevel-multiprocess models

The multilevel-multiprocess model included the following mortality equation:

(1) $\log (p_{ijt}/(1-p_{ijt})) = \gamma_0+\boldsymbol{\gamma}_1\mathbf{Y}_{ijt} + \tau_i$

where p_{ijt} is the probability that child j of mother i dies within the following 12 months given that the child had survived exactly t full years and t is between 0 and 4. This discrete-time hazard approach was chosen because a child's age at death was reported in months only up to two years, and in less detail at higher ages. Only one-year intervals completed before the interview were included.

$\mathbf{Y}_{ijt}$ is a vector of characteristics of the child (including the child's age t in one-year categories) and the household, as well as calendar year and some aggregate-level factors. See detailed description below. $\boldsymbol{\gamma}_1$ are the corresponding coefficients, and γ_0 is a constant term. τ_i is a mother-specific term that represents unobserved time-invariant characteristics. It is assumed to be drawn at random from a normal distribution with mean zero and variance σ^2_τ and affecting the mortality of all the mother's children over their first five years. Only children whose mother was 15 years or older at birth and (in most models) who were born fewer than 10 years before interview contributed in the estimation of the mortality equation. The estimation was based on 564325 one-year observations.

Two equations for birth rates were also included in the model. The equation for the first-birth rate for woman i in the year r is:

(2) $\log h_{ir}^{(1)} = \beta_0^{(1)} +\boldsymbol{\beta}_1^{(1)} \mathbf{A}_{ir}^{(1)}(a, v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8)+\boldsymbol{\beta}_3^{(1)} \mathbf{X}_{ir} +\delta_i$

and the equation for the higher-order birth rates is

(3) $\log h_{ir}^{(2)} = \beta_0^{(2)} +\boldsymbol{\beta}_1^{(2)} \mathbf{A}_{ir}^{(2)}(a, v_1', v_2', v_3', v_4', v_5')+ \boldsymbol{\beta}_2^{(2)} \mathbf{D}_{ir} (d, z_1, z_2, z_3, z_4)$
$+ \boldsymbol{\beta}_3^{(2)} \mathbf{X'}_{ir} + \boldsymbol{\beta}_4^{(2)} \mathbf{M}_{ir} +\delta_i$

Elleventh and later births were not considered. $\beta_0^{(1)}$ and $\beta_0^{(2)}$ are constants, and $\mathbf{A}_{ir}^{(1)}$ is a piecewise linear spline transformation of age (a), with nodes v_1 to v_8 at the end of the years when the woman turned 16, 18, 20, 22, 24, 29, 34, and 39, respectively. The woman contributed in the estimation from the end of the year when she turned 14[4] until the end of the year when she turned 44 or at interview, whichever came first. $\boldsymbol{\beta}_1^{(1)}$ is the corresponding vector of coefficients. Also $\mathbf{A}_{ir}^{(2)}$, which is included for second and higher-order births, is an age spline, with nodes at 19, 24, 29, 34, and 39 years, and $\mathbf{D}_{ir}$ is a spline transformation of duration (d) with four nodes at 2, 4, 6 and 8 years.[5] $\mathbf{X}_{ir}$ and $\mathbf{X'}_{ir}$ include calendar year and characteristics of the mother, household and society in which she lives. See detailed description below. There are two differences between $\mathbf{X}_{ir}$ and $\mathbf{X'}_{ir}$: Only $\mathbf{X}_{ir}$ includes an interaction between the mother's age and educational level, reflecting delayed transitions to first birth amongst the better educated, and only $\mathbf{X'}_{ir}$ includes the number of older children who had died before the time under consideration (although this had little impact on the estimates). $\mathbf{M}_{ir}$ are parity dummies (3-9, with 2 as the reference category).[6]

As in the mortality equation, there is a woman-specific random term, δ_i. (normally distributed with mean zero and variance σ^2_δ). It represents unobserved time-invariant characteristics and is assumed to be drawn at an early age and stay with the woman throughout her reproductive period, thus affecting all her birth rates.

A nonzero correlation ($\rho_{\delta\tau}$) between δ_i and τ_i was allowed, reflecting that there are joint constant mother-level determinants of fertility and child mortality. The model was estimated via maximum likelihood, using the software package aML (Lillard and Panis 2003). The distributions of the random terms were approximated by 5 support points. Increasing the number to 10 did not change the results.

Multilevel-multiprocess models of this type have been estimated in earlier investigations of strongly interlinked socio-demographic processes (Upchurch et al. 2002; Steele et al. 2009; Kravdal et al. 2013). Besides, other models with correlated fertility and mortality random terms have been used in studies of the importance of reproductive factors for child mortality in South Asia (Makepeace and Pal 2008; Saha and van Soest 2013; Bhalotra and van Soest 2008). However, fertility was modelled very differently in the latter studies, with equations for birth intervals after the first birth. Makepeace and Pal (2008), who focused on middle-order births, did not consider the importance of maternal age or birth order, and in the other studies these effects were captured by second-degree polynomials.

A simulation experiment is reported in Appendix 2. It shows that the estimation has been carried out correctly and that the results are reasonable. Additionally, it illustrates that the approach that is taken is superior to a sibling fixed-effects analysis, which also controls for constant mother-level unobserved factor, and probably would be considered by many researchers as a good alternative (and was used, for example, by Kozuki and Walker (2013) to analyse effects of the birth interval length).

Variables

The mortality equations included either separate variables for maternal age and birth order or a variable combining these two factors. In both cases, the previous birth interval was also included. It was set to the reference category, 30-41 months, for the first-born. The reference category was chosen to match the maternal age categorization and thus facilitate the discussion. The number of deaths in the different categories of these reproductive variables is shown in Table 1. A parenthesis around the number means that the group is so small that it was left out when models including the combined age-order variable were estimated. This limit was set quite arbitrarily at 0.5% of the total number of deaths.[7]

(Table 1 about here)

In addition to these three reproductive variables, calendar year and the other variables specifically mentioned earlier (child's age in the mortality equation and woman's age, duration since previous birth, parity, and mortality of older children in one or both of the fertility equations), the following variables were included in both the fertility and mortality equations: the woman's education (grouped into 0-2, 3-6, 7-8, 9-10 and 11^+ years and interacted with a grouped age variable in the equation for first birth), the woman's religion (Christian, Muslim, other/no religion), the standard DHS indicator of household wealth (based on household amenities), averages of women's education (in years completed) and household wealth calculated for the community (PSU) in which the woman lived, whether that community was urban or rural, and country dummies to capture unobserved country-specific characteristics. The mortality equation also included the child's sex.

Some of these variables may not adequately reflect the earlier situation that has influenced fertility and child mortality, as changes may have taken place between that time and the interview. In principle, variables measured at interview may even capture factors that are *consequences* of fertility or child mortality (Cohen et al., 2011). However, many of the variables are likely rather stable over the relevant period, and to the extent that there is a reverse-causality problem, it should be reassuring that all the variables are actually quite unimportant as controls (see comparison referred to in Appendix 2).

Calendar year was entered as a continuous variable with a linear effect in all models. Very similar results appeared when it instead was included as a categorical variable. Allowing the year effects to differ across countries did not change the results either.

Variations in the effects of reproductive variables

Stratified analyses were undertaken to examine some of the variation in the effects of the reproductive variables. Models were estimated separately for the 14 countries with lowest HDI (Human Development Index) and for the 14 countries with highest HDI.

"Standard" mortality models"

For reasons explained earlier, also "standard" discrete-time mortality models (referred to below as "standard mortality models") were estimated in the first steps of the analysis. Technically, this was done by leaving out the mortality random term and the (then redundant) fertility equations from the model.[8] In some of these models, only calendar year and country were included in addition to the reproductive variables and child's age; others included all the mentioned control variables.

Results

Estimates of the $\boldsymbol{\gamma}_1$ coefficients in equation (1) are presented below. These estimates reflect the log-odds of dying within a year in the category in focus minus the corresponding log-odds in the reference category, or – if the variable is continuous - how the log-odds changes with a one-unit change of that variable.

Standard mortality models with few control variables

Estimates from a standard mortality model that only included year and country as control variables are shown in Table 2 (first column). Mortality goes down with increasing maternal age until the mid-30s, after which there is an upturn. It also increases with birth order, except that mortality is higher for first-born than second-born children. Note that the coefficient for first-born reflects the difference between being a first child and being a second child born 30-41 months after the first child (the reference category for birth interval length). Furthermore, mortality falls with increasing interval length until 42-53 months; there is no further decline after that. These estimates accord with the patterns reported in several earlier analyses based on relatively simple statistical models (see above).

The general decline in mortality that is estimated from this multi-country sample without weighting is quite sharp: 0.053 per year. This figure is reasonable compared to published numbers. For example, Demombynes and Trommlerová (2012) reported that more than half of the countries in the region that had a DHS survey between 2005 and 2012 experienced an annual decline of under-5-mortality that was larger than the Millenium Development Goal of 4.4%. Similarly, a graph produced by You et al. (2015) showed an annual decline of more than 4% from 2000 to 2015, after slower improvement in the previous decade.

(Table 2 about here)

The combined “effects” (a word used here and below for simplicity and without claim of causality) of maternal age and birth order are shown in Table 3, in the form of log-odds of dying for children with various combinations of maternal age and birth order minus the corresponding log-odds for second-born children with a mother aged 21-23.[9]

(Table 3 about here)

First-born children with mothers younger than 18 have the highest mortality, but also second-born children with a mother in that age group, first-born children with a mother who is 18-20, children of birth order 7 who have a very young mother, and most of the children of birth order 8 or higher have relatively high mortality (log odds > 0.30 above the reference category). Furthermore, mortality is significantly elevated among most other children who are first-born, are of high birth order, or have a relatively young mother (i.e. who typically started childbearing early), while it is lowest among children of birth order 2 or 3 who have a relatively old mother.

First-born children do not have the same disadvantage after their first year as when they are infants. This is seen by estimating a logistic model for infant mortality and a discrete-time hazard model for mortality at age 1-4 instead of a hazard model for age 0-4 (see Panel A of Appendix table A1). In fact, child mortality at age 1-4 is rather low for first-born children with a mother in her 20s, and it is only moderately elevated if the mother is very young. Furthermore, children of birth order 2-5 who do not have a particularly young mother have a clearer advantage after their first year than earlier. Finally, short intervals have less adverse impact after the first year, while there is a more clearly protective effect of longer intervals. This accords with earlier studies of birth intervals, and may partly reflect the stronger relative importance of biological compared to social pathways among the youngest children (Manda 1999; DaVanzo et al. 2008; Fotso et al. 2012; Rutstein 2005).

The message to individual women according to standard mortality models with more control variables

As explained earlier, estimates from models that control better for joint determinants of fertility and child mortality are more useful for individual women who make fertility decisions, and for those guiding them in these matters. When many social variables are added, a less negative effect of maternal age and a less positive effect of birth order appear, while the effect of birth interval is essentially unchanged (column 2 of Table 2). The combined effects of maternal age and birth order are shown in Panel A of Table 4.

(Table 4 about here)

Below, it is explained in detail how various reproductive strategies affect child mortality and how these conclusions can be reached through a careful examination of the tables. This should pave the way for a more condense presentation of the results from the multilevel-multiprocess models later.

<u>The chance of losing the first child</u>. A woman who wants to minimize the chance of losing her first child should avoid early childbearing, assuming that future effects will be just as those

estimated. However, postponement beyond age 21 will not reduce mortality further. This and other conclusions are summarized in Table 7.

Obviously, if the general decline in mortality continues with the same force, there will be an even stronger reason to delay entry into motherhood. In that case, mortality would be lower the older the mother is, although there is a diminishing benefit of increasing age. This conclusion comes from adding the period effect to the combined effect of maternal age and birth order (see Panel B of Table 4). The period contribution is set to 0 for age group 21-24, and as a woman "moves into" a higher three-year age group, the child mortality is reduced by 0.16, which is three times the estimated per-year period effect of -0.054.[10]

Long-term implications of first-birth timing. There are also long-term implications of first-birth timing, because if the woman is relatively old when she has her first child, she will also be relatively old when she has her next children, unless she "compensates" by particularly short subsequent birth intervals. For example, if a woman has her first child when she is 18-20 and another child after a three-year interval, she will then be 21-23; if also the next interval is three years, she will be 24-26 when that child is born, and so on. Thus, she will, so to speak, move along the diagonal marked in grey. If she instead starts three years later and proceeds with three-year intervals, she will move along another diagonal one step up and to the right. One can shed light on the long-term implications of the age at first birth by, for each birth order, comparing mortality for each maternal age group with that in the higher maternal age group (i.e. check the birth-order specific effects of maternal age, which are not always monotonic). Small differences should not be counted. Below, the limit is set at 0.10, which is two times the typical standard error. (Formal significance testing would require numerous changes of the reference category and be cumbersome.)

Let us start by ignoring the possibility of a continued general mortality decline (Panel A). In that case, 5 pairwise differences are -0.10 or larger, i.e. the log-odds go down by at least 0.10 if the maternal age is in the next category. These are indicated with full underlining and appear – as do many of the smaller ones that go in the same direction – at relatively low maternal ages. There are also 3 opposite pairwise differences, i.e. differences that are 0.10 or larger. These are in the lower right part of the table (high age and birth order) and are indicated with stapled underlining. In other words, there is a U-shaped relationship between maternal age and child mortality at the highest birth order. To conclude, there is on the whole no long-term advantage to be drawn from delaying the start of childbearing into the last half of the 20s. The mortality of the first child would not be lower and the mortality of later children could be higher. If it instead is assumed that the general decline in mortality continues, the message is simpler (see panel B, with no underlining): Not only does the first child have a lower mortality the older the mother is; also the children she gives birth to later benefit from that.[11]

Net, total and long-term effects of birth intervals. When discussing which birth intervals that would be ideal, two types of effects are relevant in the short run. First, a short birth interval will itself increase the mortality of the next child. Second, if the interval is short, the mother will be slightly younger at next birth than she would otherwise be, which may have an additional impact. Let us, for example, consider a woman who has her first child when she is 18-20 and ignore the effect of the general decline in mortality. The mortality of that child, when measured as the log-odds difference from the reference category, is 0.40 (Panel A of Table 4). If the woman has another child after a three-year interval, the infant mortality of that child will be 0 (recall that 30-41 months is the reference category for birth intervals), and if she proceeds with this spacing (i.e. moves along the marked diagonal), the infant mortality of her third child will be -0.05. If she instead had her second child after an interval of less than

18 months, she would be younger at that time, which would increase infant mortality to something between 0 and 0.07 (the number to the left of the diagonal) in addition to the net adverse effect of the short birth interval (1.21). If she had yet another child after an interval of less than 18 months[12], she would be about 21-23 at third birth rather than 24-26 if she had two three-year intervals. That would give her a small disadvantage because of the lower age (0.01 as opposed to -0.05), which adds to the adverse interval effect. If she then continues with three-year intervals, each of her next children will experience a mortality quite similar to what it would be if she had started with two three-year intervals, the figures along this diagonal being -0.03, 0.00, 0.07, 0.06, and 0.26, as opposed to -0.06, -0.04, -0.05, 0.14, 0.36.

To form a more general conclusion about the “secondary” interval effect involving maternal age, we can again consider the birth-order specific effect of maternal age and conclude as above: In the absence of a general mortality decline (Panel A), being slightly older at the next birth because the birth interval is not very short is an advantage at the low ages and a disadvantage at the higher ages and birth orders. However, it is a clear advantage if there is a general mortality decline (Panel B). Taking also the longer-term implications into account, one can say that, in the presence of a general mortality decline, avoidance of a short interval gives a triple advantage: i) a beneficial net effect for the next child, ii) the mother being a bit older when that child is born, and iii) younger siblings (if any) having an older mother.[13]

Mortality of next versus previously born child. While concerns about children of high birth orders have been voiced, and the earlier description showed that these children indeed have relatively high mortality, it is not obvious how individual families and those guiding them should think about this issue. It may be relevant for them to ask whether the mortality of the *next* child would be higher than that of the most recently born child. Obviously, that would depend much on the birth intervals. Assuming first that birth intervals are always three years, the answer can be found by comparing, for each birth order and maternal age group, with mortality in the cell one step below and to the right (i.e. down along a diagonal). The conclusion is that the mortality of the next child is at least 0.10 lower for many groups of women who have less than three children. One example is shown in a box and with bold font in Panel A of Table 4). At higher birth orders, 7 opposite cases can be found. One of them is shown in a box and with standard fonts. Taking the general mortality decline into account, however, the next child will generally have a *lower* mortality (except that there are some differences below the 0.10 limit and even of the opposite sign at high age/order).

If both the interval before the child most recently born and that before the next child is very short, it is more relevant to compare with a number between the one that is lower along the diagonal and the one that is one step to the left of that. In that case, it is less clear – even if the general mortality reduction continues – that the next child will have lower mortality. Conversely, if intervals are generally long, the next child will more definitely experience a lower mortality.

The message to individual women according to the multilevel-multiprocess models

When also joint unobserved constant determinants of fertility and mortality are taken into account, the effect of calendar year is the same as estimated from the simpler models, while the effect of birth interval is somewhat weaker (column 3 of Table 2). However, effects of maternal age and birth order are markedly different. When these are included as separate variables, a sharply positive effect of maternal age appears, at least from the late teens, and mortality declines strongly with birth order.[14]

Suspicions may arise when effects are so strong, but it is important to keep in mind that high birth order goes hand in hand with high maternal age. For example, if birth intervals are 30-41 months, a prediction from these separate effects of maternal age and birth order is that, if a woman starts childbearing at age 18-20 and proceeds with three-year intervals, the log-odds of dying within a year will be 0.08 lower (-0.25+0.17) for a third child than for a second child, 0.08 lower for a fifth child, and 0.06 lower (-1.09+1.13) for children of birth order 8 or higher.

Numbers of almost the same size can be found with grey background in Panel A of Table 5, which shows effects of the variable combining maternal age and birth order. (The differences between these estimates and predictions from the main effects in column 3 of Table 2 reflect variations in the importance of maternal age across birth order. These interactions are rather weak and do not display a clear pattern.) In reality, intervals tend to be shorter than 3 years, and especially among women ending up with many children, so for a woman who started childbearing at age 18-20, an average child of birth order 8 has log-odds of dying that is closer to the number to the left of the grey diagonal (-0.24 compared to the reference category.) If a woman has a child at a considerably lower age than the one shown on the diagonal, however, the mortality of that child will be very low. Conversely, it will be high at higher ages. In fact, numbers as high as 0.4-0.6 in absolute value appear at some of the highest and lowest ages for birth orders above 1, but there are few children in these categories. The importance of maternal age is discussed in more detail below, using the same type of arguments as when presenting the result from the standard mortality model.

(Table 5 about here)

Possible "strategies" when the general mortality decline is disregarded. If the possibility of a general mortality decline is disregarded (Panel A), the advice to a woman who wants to minimize the chance of losing her first child would be to become a mother before age 24. There are also adverse implications of a higher age at first birth in the longer term, through higher maternal age at subsequent births: In fact, from this perspective, the message would be that the earlier the first birth takes place the better. All this is markedly different from the conclusions from the standard mortality model.

As mentioned, the adverse net effect of a short birth interval is weaker according to the multilevel-multiprocess model than according to the standard mortality model (0.88 as opposed to 1.10). In addition, avoidance of a short birth interval has less beneficial "secondary" effects – on the next and subsequent births - because of the mentioned increase in child mortality with increasing maternal age. Having, for example, two short intervals rather than 3-year intervals will give those two children a rather high mortality (elevated by 0.88 minus the age advantage), but if childbearing then continues with 3-year intervals, the child mortality will be as indicated by the diagonal to the left of the one on which the woman started. This advantage can be as large 0.32, but is on average round 0.15. Stated differently, the low mortality to the left of the grey diagonal (and the very low mortality one or two steps further in that direction) may come at a cost in the form of high mortality of earlier children because of short intervals. Conversely, having very long birth intervals confers only an immediate advantage, while there is a clearer long-term penalty.

One might believe that the low mortality at low ages is partly a consequence of having lost older children because of short intervals and therefore having fewer children to feed, but that appears not to be the case. Addition of an indicator of earlier child death gave *more* strongly protective effect of low maternal age, as the experience of earlier child death actually *increased* the child mortality by about 10% (perhaps partly as a result of grief reactions).

Furthermore, if all birth intervals are three years, the multiprocess-multilevel model suggests that the next child will have lower mortality than the child most recently born only among women with one or two children. The picture is mixed at higher birth orders.

The pattern changes only moderately across the first five years of a child's life. However, being a first-born child and being born after a short birth interval has a less adverse effect for children of age 1-4 than for infants (see Panel B of Appendix table A1). There is also a clearer protective effect of a rather long interval.

<u>Possible "strategies" when the general mortality decline is taken into account</u>. The conclusions are quite different if the general decline in mortality is assumed to continue with the same strength (Panel B): First, the mortality of the first child is minimized by becoming a mother after age 18. There is little variation in mortality across ages above that. Second, there is not a clear long-term effect of a higher age at first birth and "secondary effect" of avoiding short birth intervals. In fact, there are quite few examples that a higher age matters, and on the whole these tilt towards the adverse side. Thus, in comparison with the standard mortality models (when continued mortality decline is assumed), everything points towards fewer advantages from starting childbearing relatively late and not having short birth intervals. Third, if all birth intervals are three years, the next child will generally have lower mortality than the child most recently born. (Only a few differences are smaller than 0.10.) If intervals are generally shorter or generally longer, the conclusion is basically the same, since maternal age matters little.

Longer period of analysis and variations in effects

Appendix table A2 shows estimates from a model where all births to the interviewed women are included, also those occurring more than 10 years before interview. Effects of maternal age and birth order are somewhat weaker (separate effects not shown), and the general mortality decline is also weaker, but the conclusions about fertility strategies would be the same.

According to models estimated separately for the countries with lowest and those with highest HDI - and with the focus again on births within the most recent 10 years – a long birth interval has more protective effect in the richest countries (Table 6).[15] Otherwise, the estimates differ little.

(Table 6 about here)

Summary and Conclusion

The importance of reproductive factors for infant and child mortality has received much attention over many years, and the issue is still highly relevant in many parts of the word, not least in sub-Saharan Africa. However, whereas a sharply adverse effect of a short birth interval has been reported consistently, there is much uncertainty about the other reproductive factors. A number of individual and societal characteristics that are hard to measure affect both fertility and mortality, so conclusions from earlier investigations may be questioned, and results from studies that have dealt with selection in the most advanced way have given diverging results.

For some purposes, identification of causal effects may not even be a goal. In the present study, a model that only controls for period and country was therefore estimated, using DHS data from sub-Saharan Africa. This analysis showed that first-born children with a mother younger than 18 and those born after very short intervals have the highest mortality. High mortality was also observed among second-born children with a mother in that age group, first-born children with a mother aged 18-20, children of birth order 7 who have a very young mother, and most of the children of birth order 8 or higher. Mortality was lowest among children of birth order 2 or 3 who have a relatively old mother.

Adding a number of social control variables did not change the picture much. However, estimates from multilevel-multiprocess models that control for constant unobserved characteristics of the mother (and her household and the society in which she lives) pointed in a rather different direction. In short, late childbearing and long birth intervals are less of an advantage according to the multilevel-multiprocess model than according to the standard model, and an even lower mortality or the next child compared to the most recently born child appears with the former. See summary of effects in Table 7.

(Table 7 about here)

To be more specific, there are three messages from the multilevel-multiprocess analysis. One is that it would actually be a disadvantage for a first child to have a mother older than about 24, unless the general decline in mortality continues. If it does, and with the same strength, the advice would be to avoid entry into motherhood before age 18, while further postponement matters little. There are also adverse long-term implications of a higher age at first birth: the older the mother is at first birth, the older she will be at later births, and the higher is the child mortality. This pattern is hardly visible, however, if the secular mortality decline continues. It is, of course, difficult to give advice in this situation. Mortality fell more sharply during the study period than in preceding years, and it is far from obvious that this positive development will continue.

Secondly, there is a beneficial net effect of avoiding a short interval, although not as sharp as according to the standard model. As just mentioned, however, the "secondary effect" operating through a slightly higher maternal age at next and later births is adverse unless there is a continued secular mortality decline (in which case maternal age matters little). Stated differently, if a woman has her first children after relatively short birth intervals, those children will have high mortality, but later children will benefit from her lower age. In fact, children of high birth order who have relatively young mothers – typically as a result of a combination of relatively early start of childbearing and short earlier intervals – have markedly lower mortality than most other children if they themselves are born after a moderate or long interval (i.e. the mother has increased her birth intervals).

Thirdly, in the absence of a continued mortality decline, most estimates suggest that a woman's next child will have a lower chance of dying than the child most recently born, assuming that birth intervals are the same". (This appears more clearly than with the standard model.) Obviously, if the recent mortality decline continues, the advantage of the next child is even stronger. However, although a woman may not need to be particularly concerned about the mortality of higher-order children, high birth order could weaken the child's health in the longer term or cause socioeconomic disadvantages for other reasons. That is beyond the scope of this analysis.

The adverse effect of a higher maternal age that appears from the multilevel multiprocess models and is an element of the conclusions just mentioned may be considered surprising, or at least surprisingly strong. However, an effect in this direction is theoretically plausible: There may be an accumulation of maternal health problems over age (Geronimus 1992) that outweighs various physiological and social advantages that have attracted more attention in this literature. Besides, adverse effects of maternal age from a quite low age or over the entire age span have been reported also in earlier studies of child mortality in a general poor population (Saha and van Soest 2013) or in a disadvantaged sub-group in rich settings (Powers 2013). Such effects have appeared also in studies of birth weight among minority groups in the US (Love et al., 2010) and the UK (Goisis and Sigle-Rushton, 2014). Additionally, the protective effect of higher birth order – which can be seen as counteracting the age effect so that a next child does not have a markedly higher mortality than the previously born child - has been reported in earlier studies (Kudamatsu et al., 2012). A possible explanation is that parents accumulated experience with childrearing, although it may seem unlikely that this benefit is so large. Moreover, in addition to being plausible and in line with some earlier studies, the findings are robust to many alternative model specifications, and the simulation experiment indicates that the estimation has been carried out appropriately. The fact that the results do not vary across the two main groups of countries that are considered suggests that the processes involved are either quite general or that interactions with the socioeconomic development (a few possible examples were given above) cancel each other out.

Unfortunately, the multilevel-multiprocess model does not control perfectly for selection, as factors that vary over time within a family are not accounted for. For example, a mother may not be particularly "childbearing prone" when she has her third child at age 25, but may for some reason see the world differently some years later or have poorer access to contraception, and thus continue childbearing beyond the original intentions, perhaps even at higher speed. Her health or her breastfeeding pattern may also have changed over time, with implications for her ability to have or interest in having another child soon. Such factors can obviously also affect the mortality of her children (although some studies that have controlled for breastfeeding have shown that this factor does not matter much; DaVanzo et al., 2008; Rutstein 2005). Given these methodological concerns as well as the importance of the subject and the somewhat challenging results from this study – which suggest that there may be much more to story about maternal age and birth order than commonly thought - further analysis based on even richer data and better methods should be very welcome.

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Table 1. Number of deaths by birth order, maternal age, and length of preceding birth interval among children younger than 5 years and born less than 10 years before DHS interviews in 28 countries in sub-Saharan Africa.[1]

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+	Sum
1	3001	3574	1721	728	294	(163)	(55)	(24)	(8)	(1)	9569
2	434	2242	2420	1205	557	257	(119)	(49)	(18)	(5)	7306
3	(9)	627	1856	1665	898	425	200	(95)	(45)	(12)	5832
4		(88)	799	1369	1214	742	371	(148)	(69)	(26)	4816
5		(13)	(183)	707	1051	889	520	269	(129)	(39)	3798
6		(1)	(19)	225	635	833	596	375	203	(69)	2958
7			(7)	(38)	268	526	556	454	276	(93)	2218
8+			(1)	(22)	(86)	360	630	645	914	474	3432
Sum	3444	6535	7006	5961	5023	4195	3047	2359	1662	719	39931

Preceding interval (months)	
-17	5563
18-23	6427
24-29	6720
30-41[2]	16146
42-53	2492
54-	2583

Notes:
[1] Numbers in parentheses are less than 0.5% of the total
[2]Preceding birth interval is set to 30-41 if birth order is 1.

Table 2. Effects (log odds with SE) of maternal age, birth order, length of preceding birth interval, and calendar year on mortality among children younger than 5 years and born less than 10 years before DHS interviews in 28 countries in sub-Saharan Africa.

	Discrete-time mortality model also including child's age and country	Discrete-time mortality model also including child's age, country and several other variables (see text)	Multilevel-multiprocess model also including child's age, country and several other variables (see text)
	(fertmort23mod40)	(fertmort23mod22)	(fertmort23mod20)
Maternal age (years)			
15-17	0.38*** (0.02)	0.30*** (0.02)	-0.04 (0.03)
18-20	0.12*** (0.02)	0.08*** (0.02)	-0.12*** (0.02)
21-23[1]	0	0	0
24-26	-0.07*** (0.02)	-0.03 (0.02)	0.17*** (0.02)
27-29	-0.14*** (0.02)	-0.06*** (0.02)	0.33*** (0.02)
30-32	-0.17*** (0.02)	-0.06*** (0.02)	0.52*** (0.03)
33-35	-0.26*** (0.03)	-0.14*** (0.03)	0.63*** (0.03)
36-38	-0.21*** (0.03)	-0.08*** (0.03)	0.84*** (0.04)
39-41	-0.11*** (0.03)	0.01 (0.03)	1.03*** (0.04)
42+	-0.04 (0.04)	0.06 (0.04)	1.20*** (0.06)
Birth order			
1	0.26*** (0.02)	0.32*** (0.02)	0.53*** (0.02)
2[1]	0	0	0
3	0.03 (0.02)	-0.03 (0.02)	-0.25*** (0.02)
4	0.11*** (0.02)	0.01 (0.02)	-0.43*** (0.02)
5	0.19*** (0.02)	0.05** (0.02)	-0.60*** (0.03)
6	0.28*** (0.03)	0.12*** (0.02)	-0.73*** (0.03)
7	0.39*** (0.03)	0.21*** (0.03)	-0.83*** (0.03)
8+	0.52*** (0.03)	0.31*** (0.03)	-1.09*** (0.04)
Preceding interval (months)[2]			
-17	1.01*** (0.02)	1.00*** (0.02)	0.88*** (0.02)
18-23	0.60*** (0.02)	0.59*** (0.02)	0.52*** (0.02)
24-29	0.33*** (0.02)	0.32*** (0.02)	0.26*** (0.02)
30-41[1]	0	0	0
42-53	-0.21*** (0.03)	-0.20*** (0.02)	-0.15*** (0.02)
54-	-0.20*** (0.03)	-0.16*** (0.02)	-0.11*** (0.03)
Year	-0.053*** (0.002)	-0.052*** (0.002)	-0.054*** (0.002)
Standard deviation of δ (σ_{δ})			0.43*** (0.00)
Standard deviation of τ (σ_{τ})			0.90*** (0.01)
Correlation between δ and τ ($\rho_{\delta\tau}$)			0.75*** (0.01)

Notes:
[1] *Reference category*
[2]*Preceding birth interval is set to 30-41 if birth order is 1.*

****p<0.01; ** p<0.05; * p<0.010*

Table 3. Effects (log odds) of maternal age and birth order on mortality among children younger than 5 years and born less than 10 years before DHS interviews in 28 countries in sub-Saharan Africa. Discrete-time mortality model also including length of preceding birth interval, calendar year, country dummies and child's age. [1]
(fertmort23mod41.aml)

Birth order	Maternal age (years)									
	15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.66***	0.38***	0.20***	0.18***	0.08					
2	0.30***	0.11***	0[2]	-0.07**	-0.13***	-0.14**				
3		0.13***	0.05	-0.04	-0.15***	-0.22***	-0.22***			
4			0.15***	0.01	-0.04	-0.05	-0.08			
5				0.11***	0.05	-0.02	-0.02	-0.06		
6				0.23***	0.17**	0.11**	-0.02	0.08	0.11	
7					0.33***	0.21***	0.11**	0.17***	0.26***	
8+						0.33***	0.18***	0.33***	0.43***	0.48***

Notes:
[1] *Standard errors of the combined effects of maternal age and birth order are 0.03 – 0.07 (largest in the smallest groups, see Table 1). Effects of birth interval are 1.01, 0.60, 0.32, -0.20 and -0.21, and the effect of calendar year is -0.053, with standard errors as in column1 of Table 2.*
[2] *Reference category*

****p<0.01; ** p<0.05; * p<0.010*

Table 4. Effects (log odds) of maternal age and birth order on mortality of children younger than 5 year and born less than 10 years before DHS interviews in 28 countries in sub-Saharan Africa. Discrete-time mortality model also including length of preceding birth interval, calendar year, country dummies, child's age and several other variables (see text).

PANEL A: Model estimates[1]
(fertmort23Mod42).

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.64***	0.40***	0.27***	0.31***	0.27***					
2	0.23***	0.07**	0[2]	-0.03	**-0.03**	-0.02				
3		0.06	0.01	-0.05	-0.12***	**-0.16*****	-0.15**			
4			0.07*	-0.03	-0.06*	-0.04	-0.06			
5				0.04	0.00	-0.04	-0.03	-0.07		
6				0.15**	0.10**	0.07*	-0.05	0.05	0.08	
7					0.24***	0.14**	0.06	0.14***	0.22***	
8+						0.24***	0.11**	0.26***	0.36***	0.40***

PANEL B: Sum of the period effect (set to 0 for age 21-23) and the combined effect of maternal age and birth order shown in panel A.

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.96	0.56	0.27	0.15	-0.05					
2	0.55	0.23	0[2]	-0.19	-0.35	-0.51				
3		0.22	0.01	-0.21	-0.44	-0.65	-0.80			
4			0.07	-0.19	-0.38	-0.54	-0.71			
5				-0.12	-0.32	-0.53	-0.68	-0.88		
6				-0.01	-0.22	-0.42	-0.70	-0.76	-0.89	
7					-0.08	-0.35	-0.59	-0.67	-0.75	
8+						-0.25	-0.54	-0.55	-0.61	-0.73

Notes:
[1] *Standard errors of the combined effects of maternal and birth order are 0.03 – 0.07 (largest in the smallest groups, see Table 1). Effects of birth interval are 1.01, 0.58, 0.31,0, -0.19 and -0.18, and the effect of calendar year is -0.054, with standard errors as in column 2 of Table 2. The symbols ___ and .... indicate examples of differences of ≤ - 0.1 or ≥ 0.1, respectively, when comparing two cells horizontally and the value in the left cell is subtract from that in the right. The boxes indicate examples of differences of ≤ -0.1 (**bold** font) or ≥0.1(standard font) when comparing two cells along a diagonal and the value in the upper left cell is subtracted from that in the lower right.*
[2] *Reference category*

****p<0.01; ** p<0.05; * p<0.010*

Table 5. Effects (log odds) of maternal age and birth order on mortality of children younger than 5 years and born less than 10 years before DHS interviews in 28 countries in sub-Saharan Africa. Multilevel-multiprocess model also including length of preceding birth interval, calendar year, country dummies, child's age and several other variables (see text).

PANEL A: Model estimates[1]
(fertmort23mod43).

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.49***	0.41***	0.48***	0.72***	0.80***					
2	-0.13**	-0.15***	0[2]	0.18***	0.34***	0.50***				
3		-0.40***	-0.24***	-0.07	0.07*	0.19***	0.34***			
4			-0.43***	-0.30***	-0.08**	0.13**	0.26***			
5				-0.48***	-0.28***	-0.09	0.11**	0.21***		
6				-0.63***	-0.42***	-0.21**	-0.12**	0.15***	0.30***	
7					-0.51***	-0.37***	-0.24***	0.03	0.25***	
8+						-0.59***	-0.56***	-0.24***	-0.05	0.10*

PANEL B: Sum of the period effect (set to 0 at age 21-23) and the combined effect of maternal age and birth order shown in panel A.

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.83	0.58	0.48	0.55	0.46					
2	0.21	0.02	0[2]	0.01	0.00	0.00				
3		-0.23	-0.24	-0.24	-0.27	-0.31	-0.33			
4			-0.43	-0.47	-0.42	-0.37	-0.41			
5				-0.65	-0.62	-0.59	-0.56	-0.63		
6				-0.80	-0.76	-0.71	-0.79	-0.69	-0.71	
7					-0.85	-0.87	-0.91	-0.81	-0.76	
8+						-1.09	-1.23	-1.08	-1.06	-1.08

Notes:
[1] Standard errors of the combined effects of maternal age and birth order are 0.03 – 0.08 (largest in the smallest groups, see Table 1). The effects of birth interval are 0.88, 050, 0.26, 0, -0.14 and -0.12, and the effect of calendar year is -0.056, with standard errors as in column 3 of Table 2. The standard deviations of the random terms are 0.42 and 0.89, and the correlation between them is 0.77.
[2] Reference category

****p<0.01; ** p<0.05; * p<0.010*

Table 6 . Effects (log odds with SE) of maternal age, birth order, length of preceding birth interval and calendar year on mortality of children younger than 5 years and born less than 10 years before DHS interviews in two subgroups of 28 countries in sub-Saharan Africa. Multilevel-multiprocess model also including country dummies, child's age and several other variables (see text).

fertmort23mod20poor for low HDI, mod20rich for high HDI,

	Countries with lowest HDI	Countries with highest HDI
Maternal age (years)		
15-17	-0.07* (0.04)	-0.01 (0.04)
18-20	-0.14*** (0.03)	-0.11** (0.03)
21-23[1]	0	0
24-26	0.18*** (0.03)	0.16*** (0.03)
27-29	0.38*** (0.04)	0.29*** (0.03)
30-32	0.55*** (0.04)	0.49*** (0.04)
33-36	0.66*** (0.05)	0.59*** (0.04)
36-38	0.88*** (0.06)	0.80*** (0.05)
39-41	1.08*** (0.07)	0.98*** (0.06)
42+	1.24*** (0.08)	1.15*** (0.08)
Birth order		
1	0.52*** (0.03)	0.54*** (0.03)
2[1]	0	0
3	-0.26*** (0.03)	-0.24*** (0.03)
4	-0.43*** (0.04)	-0.42*** (0.03)
5	-0.64*** (0.04)	-0.55*** (0.04)
6	-0.74*** (0.05)	-0.71*** (0.04)
7	-0.85*** (0.06)	-0.81*** (0.05)
8+	-1.09*** (0.07)	-1.07*** (0.06)
Preceding interval (months)[2]		
-17	0.89*** (0.03)	0.87*** (0.03)
18-23	0.52*** (0.03)	0.49*** (0.03)
24-29	0.27*** (0.03)	0.25*** (0.03)
30-41[1]	0	0
42-53	-0.11*** (0.04)	-0.17*** (0.03)
54-	-0.01 (0.04)	-0.20*** (0.03)
Year	-0.041*** (0.003)	-0.064*** (0.003)
Standard deviation of δ (σ_{δ})	0.46*** (0.01)	0.41*** (0.01)
Standard deviation of τ (σ_{τ})	0.90*** (0.02)	0.89*** (0.02)
Correlation between δ and τ ($\rho_{\delta\tau}$)	0.71*** (0.02)	0.78*** (0.02)

Notes:
[1] *Reference category*
[2] *Preceding birth interval is set to 30-41 if birth order is 1.*

****p<0.01; ** p<0.05; * p<0.010*

Table 7. Summary of effects on child mortality.

	According to standard mortality model		According to multilevel-multiprocess model	
	Ignoring mortality decline	Assuming mortality decline as earlier	Ignoring mortality decline	Assuming mortality decline as earlier
	Based on Table 4 Panel A	*Based on Table 4 Panel B*	*Based on Table 5 Panel A*	*Based on Table 5 Panel B*
Effect of maternal age on mortality of first child	- until age 21	-	+ after age 24	- until age 18
Higher maternal age at second or later birth, as implication of -later first birth -longer preceding interval -longer interval earlier	mixed (- at low age + at high age/order)	-	+	0 (few + and fewer -, mostly at high order)
Net effect of longer interval	-		- but not quite as sharp	
Next child compared to previous, if intervals always 3 years	mixed (- at low order + especially at high age/order) at high age/order)	- except at high age/order	- at low order mixed at high order	- with fewer exceptions

Appendix 1: Two tables

Table A1. Effects (log odds) of maternal age and birth order on infant and child mortality up to age 5 among infants and children born less than 10 years before DHS interviews in 28 countries in sub-Saharan Africa.[1]

PANEL A: Logistic or discrete-time mortality model also including length of preceding birth interval, calendar year, country dummies and (for age 1-4) child's age.
(fertmort23mod3xy.aml)

<u>Infants</u>

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.89***	0.60***	0.38***	0.41***	0.32***					
2	0.37***	0.12**	0[2]	-0.02	-0.09	-0.03				
3		0.15**	0.04	-0.09**	-0.11**	-0.20***	-0.12			
4			0.22***	-0.04	-0.02	-0.03	0.02			
5				0.04	0.04	-0.01	0.11*	0.02		
6				0.29***	0.17**	0.14**	0.08	0.13*	0.25***	
7					0.44***	0.23***	0.15**	0.29***	0.35***	
8+						0.40***	0.22***	0.41***	0.45***	0.55***

<u>Children of age 1-4</u>

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.28***	0.02	-0.09*	-0.23***	-0.35***					
2	0.21***	0.09*	0[2]	-0.16***	-0.18**	-0.34***				
3		0.11	0.06*	0.03	-0.21***	-0.25***	-0.41***			
4			0.05	0.07	-0.06	-0.09	-0.25**			
5				0.21***	0.06	-0.03	-0.25***	-0.19*		
6				0.17	0.19***	0.07	-0.18**	-0.01	-0.12	
7					0.18*	0.19**	0.06	-0.01	0.13	
8+						0.25***	0.14	0.21***	0.39***	0.38***

Notes:
[1] *Standard errors of the combined effects of maternal age and birth order are 0.04 – 0.09 (largest in the smallest groups, see Table 1). For infants, the effects of <u>birth interval</u> are 1.23, 0.72, 0.39,0, -0.16 and -0.10 (with standard errors 0.02-0.03), and for children aged 1-4, the effects of <u>birth interval</u> are 0.63, 0.42, 0.22, 0, -0.24 and -0.33 (with standard errors 0.03-0.04). Effects of calendar year are -0.050 and -0.065, respectively.*
[2] *Reference category*

****p<0.01; ** p<0.05; * p<0.010*

PANEL B: Multilevel-multiprocess model also including length of preceding birth interval, calendar year, country dummies, (for age 1-4) child's age, and several other variables (see text). (fertmort23mod2x.aml, but changed ref group).[3]

<u>Infants</u>

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.74***	0.64***	0.66***	0.91***	1.00***					
2	-0.05	-0.13**	0[2]	0.23***	0.36***	0.58***				
3		-0.37***	-0.23***	-0.11**	0.11*	0.26***	0.44***			
4			-0.33***	-0.33***	-0.06	0.16**	0.36***			
5				-0.52***	-0.26***	-0.07	0.25***	0.29***		
6				-0.55**	-0.41***	-0.16**	-0.06	0.22***	0.44**	
7					-0.37***	-0.33***	-0.19***	0.16**	0.36***	
8+						-0.50***	-0.49***	-0.13**	0.00	0.20***

<u>Children of age 1-4</u>

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.09	0.05	0.22***	0.37***	0.48***					
2	-0.24**	-0.19***	0[2]	0.12*	0.34***	0.37***				
3		-0.46***	-0.26***	-0.01	0.03	0.19**	0.20			
4			-0.58***	-0.26***	-0.10	0.11	0.12			
5				-0.31***	-0.28***	-0.11	-0.12	0.09		
6				-0.72***	-0.42***	-0.27***	-0.28***	0.06	0.06	
7					-0.71***	-0.42***	-0.30***	-0.17*	0.12	
8+						-0.73***	-0.64***	-0.39***	-0.12	-0.03

Notes:

[3] The multilevel-multiprocess model included one equation for infant mortality and one for mortality at age 1-4, both with the same unobserved factor. Otherwise, the model was as described earlier. Using two different unobserved factors and allowing both of them to be correlated with the unobserved factor in the fertility equation gave the same results. Standard errors of the combined effects of maternal age and birth order are 0.05 – 0.14 (largest in the smallest groups, see Table 1). For infants, the effects of <u>birth interval</u> are 1.06, 0.61, 0.31,0, -0.10 and -0.02 (with standard errors 0.02-0.03), and for children aged 1-4, the effects of <u>birth interval</u> are 0.49, 0.33, 0.15, 0, -0.18 and -0.25 (with standard errors 0.03-0.04). Effects of calendar year are -0.051 and -0.067, respectively. The standard deviations of the heterogeneity terms are 0.43 and 0.88, and the correlation between them is 0.77.

****p<0.01; ** p<0.05; * p<0.010*

Table A2. Estimates from a model such as specified in panel A of Table 5, except that also children born more than 10 years before interview are included. [1] (fertmort23mod44)

Birth order	Maternal age (years) 15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42+
1	0.41***	0.35***	0.39***	0.55***	0.68***					
2	-0.07**	-0.11***	0[2]	0.08***	0.33***	0.43***				
3		-0.25***	-0.19***	-0.03	0.06**	0.19***	0.32***			
4			-0.31***	-0.18***	-0.05**	0.15***	0.31***			
5				-0.35***	-0.18***	-0.02	0.16***	0.28***		
6				-0.47***	-0.34***	-0.17***	-0.04	0.20***	0.31***	
7					-0.43***	-0.30***	-0.15***	0.04	0.28***	
8+						-0.46***	-0.39***	-0.18***	-0.02	0.08

Preceding interval (months)[3]		
-17	0.77***	(0.01)
18-23	0.44***	(0.01)
24-29	0.23***	(0.01)
30-41[2]	0	
42-53	-0.16***	(0.01)
54-	-0.22***	(0.01)

Year	-0.028***	(0.001)

Notes:

[1] *Standard errors of the age/order effects are 0.03 – 0.12 (and largest in the smallest groups, see Table 1). The standard errors of the heterogeneity terms are 0.44 and 0.82, and the correlation between them is 0.79.*

[2] *Reference category*

[3] *Preceding birth interval is set to 30-41 if birth order is 1.*

****p<0.01; ** p<0.05; * p<0.010*

Appendix 2: Simulation

A sample was set up as the first step of the simulation experiment: 600000 women were distributed across years of interview, age, and education in accordance with the corresponding distributions of the DHS surveys. (The multilevel-multiprocess models could not be estimated with a larger sample.)

In the second step, a simplified multilevel-multiprocess model was estimated from the DHS data. It included the reproductive variables, year, child's age and mother's education in the mortality equations and mother's age and education, time since birth and year in the fertility equations. For simplicity, birth order and maternal age were treated as two separate variables rather than combining them into one variable. The estimates from this model, which are shown in the first column of Appendix table A3 (and are quite similar to those shown in column 3 of Table 2 from a model with more variables), were taken as effect parameters in the simulation, except that effects for one-year categories of maternal age were obtained by interpolation and extrapolation (see details in notes to Appendix table A3).

In the simulation, birth rates were predicted for each month of life for each woman in the sample, taking also into account the mortality and fertility random terms, which were drawn from a bivariate normal distribution according to the estimated covariance structure. A one-month birth probability was calculated from each of these birth rates, and fertility histories were then generated from these probabilities. Births of order above 10 were ignored. The distributions of the simulated births over maternal age, birth order and birth interval length were very similar to the corresponding distributions of the births in the DHS data (not shown in tables).

Third, a multilevel-multiprocess model (specified such as in the estimation just described) was estimated from the simulated birth histories. The estimates (column 2 of Appendix table A3) did not differ much from the parameters used in the simulation, which indicates that the program used to adapt data to aML works well and that aML, not surprisingly, does what it is supposed to do.

Fourth, a standard discrete-time mortality model was estimated from the simulated birth histories (column 3 of Appendix table A3). The estimates were quite similar to those obtained when the same model was estimated from DHS data (column 4 of Appendix table A3) or when more control variables were included (column 2 of Table 2). In other words, the relatively weak relationships between child mortality and high maternal age and high birth order that appear in simpler analysis – and that have been reported in some earlier studies - are consistent with a sharply positive effect of high maternal age, a sharply negative effect of high birth order, and a positive correlation between constant woman-specific mortality and fertility random terms, such as found with the multilevel-multiprocess model estimated from DHS data.

A sibling model (i.e. a mortality model with mother-level fixed effects) might be seen by many researchers as a reasonable alternative. It is worth noting that it does not give correct estimates. Less positive effects of high maternal age are obtained with such a model (column 5 of Appendix table A3), and the year effect is much smaller, while effects of birth order and birth interval are the same. (Using a much larger simulation sample gave similar results.) An intuitive explanation of this is that the increase in mortality within a 3-year category of mother's age is partly attributed to the period effect. In contrast, the period effect is estimated correctly with the multilevel-multiprocess approach, which not in the same way is a comparison between siblings, but also makes use of data on children without siblings and allows inclusion of factors that do not vary across siblings. A bias in the period effect has implications especially for the estimation of effects of maternal age. If broader categories of maternal age are used, the sibling model gives even more biased estimates (column 6 of

Appendix table A3).[16] Also a fixed-effect proportional hazard (Cox) model was estimated from the simulated birth histories, after adding months of death at random. The results were similar to those obtained with a sibling model (not shown in tables).

Table A3. Results from simulation experiments (only point estimates shown)

	Effect parameters used in the simulation[1]	Multilevel-multiprocess model estimated from simulated births[2]	Standard mortality model estimated from simulated births[3]	Standard mortality model estimated from DHS data[3]	Sibling mortality models estimated from simulated births[3,4]	
	(simul30, from fertmort23mod30 which gives the same as in Tab3 except ctrl social)	(simul30 buildsimul16 fertsimul16.r2a fertsimul30.aml)	(same)	(same as tab2 col 1, except ctrl educ and not country)	(simul30)	
Mother's age						
15-17	-0.02	-0.02	0.37	0.36	0.11	0.03
18-20	-0.12	-0.07	0.15	0.10	-0.01	
21-23[5]	0	0	0	0	0	0
24-26	0.17	0.18	-0.06	-0.06	0.11	
27-29	0.35	0.36	-0.10	-0.11	0.21	0.08
30-32	0.55	0.52	-0.15	-0.13	0.31	
33-35	0.67	0.67	-0.20	-0.21	0.39	0.12
36-38	0.89	0.83	-0.21	-0.16	0.49	
39-41	1.10	1.00	-0.14	-0.07	0.58	0.16
42-44	1.26	1.18	-0.07	-0.02	0.60	
Birth order						
1	0.54	0.54	0.27	0.30	0.68	0.73
2[5]	0	0	0	0	0	0
3	-0.26	-0.26	0.00	0.00	-0.28	-0.29
4	-0.46	-0.44	0.06	0.06	-0.47	-0.48
5	-0.65	-0.63	0.11	0.12	-0.67	-0.69
6	-0.80	-0.76	0.22	0.20	-0.81	-0.83
7	-0.94	-0.90	0.30	0.30	-0.99	-1.01
8+	-1.25	-1.16	0.44	0.42	-1.25	-1.27
Birth interval						
-17	0.83	0.84	0.85	0.99	0.96	0.98
18-23	0.50	0.49	0.55	0.61	0.57	0.57
24-29	0.25	0.24	0.27	0.33	0.28	0.28
30-41[5]	0	0	0	0	0	0
42-53	-0.14	-0.15	-0.20	-0.20	-0.17	-0.17
54-	-0.10	-0.10	-0.18	-0.19	-0.14	-0.14
Year	-0.043	-0.043	-0.040	-0.039	-0.018	0.005
<u>Random terms</u>						
St. dev. of δ	0.47	0.46				
St. dev. of τ	0.99	0.99				
Corr. between δ and τ	0.79	0.77				

Notes:
[1] These parameters are estimates of effects/coefficients in a multilevel model including only the age, duration since birth, parity, year and education in the fertility equation, and maternal age and edcuation, birth order,

birth interval, year, and child's age in the mortality equation (i.e. as in column 3 of Table 2, except that education is the only variable in addition to the "core" demographic variables). The model was estimated from DHS data. The parameter for a middle one-year age category (e.g. 31) of a three-year category of maternal age (e.g. 30-32) is set to the estimate for that three-year category, which is shown in column 1 of the table. Parameters for the other one-year categories are obtained by linear inter- and extrapolation from the parameters for the middle one-year categories.

[2] *The model includes the same variables as described in note1.*

[3] *The model includes the same variables as in the mortality equation in the multilevel-model on which the simulation was based, i.e. birth order, mother's age and education, birth interval, year, and child's age. In the fixed-effects model, maternal education cancels out.*

[4] *Pairs of maternal age categories are grouped together*

[5] *Reference category*

Endnotes

[1] The surveys have used a stratified cluster sample design. Within each province, a number of primary sampling units (PSUs) have been selected. These units typically encompass one or a few villages or part of a town. On average, about 25 households have been randomly selected within each primary sampling unit, and women of reproductive age in the household have been interviewed.

[2] Women with twins were included in some additional calculations. The number of pregnancies resulting in live births was then considered, along with a twin indicator. The results were very similar.

[3] It has been observed that some women report a higher age for a child born a little less than five years before interview to avoid answering so many detailed questions. This may be particularly common if the child has died (Pullum 2006), which, in principle, could blow up the adverse effects of short birth intervals.

[4] Thus, if a woman had her first birth at age 13 and then no other birth before the end of the year when she turned 14, she only contributed to the estimation of the equation for second- and higher-order births, and from the latter age.

[5] A linear trend in the birth rate from 0 to 24 months is not realistic, but adding a node at 8 months gave almost identical results.

[6] A restriction implied by the equations above is that effects of **A**, **D** and **X'** are the same at all parities above 1. The results were similar if the effects were allowed to vary.

[7] If these groups were left out also when estimating separate effects of maternal age and birth order, the results were almost unchanged.

[8] These simpler models could, of course, also be estimated directly from the data fed into aML, using the same software as when preparing these data (SAS). Alternatively, one might keep the mortality random term and omit the fertility equation (essentially the same as setting the correlation between the two random terms to zero). Thus, there would still be an unobserved factor affecting the mortality of all siblings, but not linked to fertility. This gave almost identical results.

[9] Addition of the separate effects of maternal age and birth order shown in the first column of Table 2 gave the same pattern, except for a lower mortality at the lowest maternal ages for birth orders 4 and 6-8 (not shown).

[10] If mother's year of birth was included instead of child's year of birth, the combined effects of maternal age and birth order were very similar to those shown in Panel B of Tables 4 and 5, as maternal age then picked up also the period effect.

[11] Conclusions about long-term effects could alternatively have been reached by including age at first birth instead of current age for birth orders above 1 in the mortality equation.

[12] In fact, the high mortality of the second-born child, primarily because of the short preceding birth interval, itself increases the chance of a short subsequent interval.

[13] To reach such conclusions, one could alternatively include age at *previous* birth and length of preceding interval in the model, as well as mother's birth cohort instead of year of birth if the intention is to let the two other variables pick up the period effect.

[14] If a broader categorization of maternal age and birth order was used, effects were weaker. This is because differences in child mortality within a birth-order category are attributed to the effect of maternal age, which then becomes less positive, and vice versa.

[15] This could be partly a selection effect: In that setting, a long interval may to a lesser extent be the result of an adverse pregnancy outcome that may reflect poor maternal health or other problems of importance for child mortality.

[16] Further broadening of the categories gives weaker effects of maternal age also when a multilevel-multiprocess model is estimated, but the differences are much smaller than with a sibling model, and the estimate of the year effect changes only moderately. Note also that one cannot estimate discrete-time fixed effects models with one-year categories for maternal age, while this would work well with the multilevel-multiprocess approach.