The effect of HIV/AIDS on the own child-method of estimating child mortality: Lesotho and Zimbabwe

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A dissertation submitted to the faculty of Commerce of the University of Cape Town in partial fulfilment of the requirements for the Degree of Master of Philosophy in Demography

September 2011

PLAGIARISM DECLARATION

This research is my original work, produced with supervisory assistance from my supervisor. I have used the Harvard convention for citation and referencing. Each contribution from the works of other people has been cited and referenced. This dissertation has not been submitted for any academic or examination purpose at any other university.

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Herbert Musariri Date

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Professor Rob Dorrington, for his tireless efforts, invaluable ideas and insightfulness. I thank Associate Professor Tom Moultrie for the knowledge and skills he imparted to me during coursework.

The support and encouragement of my family, friends and classmates is greatly appreciated. Special thanks go to my wife Sikoshiwe, my son Herbert (Jnr), and my daughter Tariro, for their patience and support during the time of my studies.

I extend my gratitude to the Hewlett Foundation and the University of Cape Town, Postgraduate Funding Office for funding my studies and stay in Cape Town.

ABSTRACT

This study evaluates the overall impact of the bias due to HIV/AIDS on the own-child method of estimating child mortality, and the contribution of the various components to the overall bias.

Indirect estimates of child mortality are calculated by applying the own-child method to the 2009 Lesotho Demographic and Health Survey (LDHS) and the 2005-6 Zimbabwe DHS. In the process, the potential of the software, MATCHTAB, to link successfully surviving children to their biological mothers is demonstrated using the 2006 Lesotho census data. To evaluate the impact of HIV/AIDS on the own-child method, the target estimates of child mortality for Lesotho and Zimbabwe are also developed by adjusting the direct estimates from the full history data for the selection bias introduced by HIV/AIDS.

While the overall bias due to HIV/AIDS induces a significant underestimation of child mortality, its impact appears to be diminished by the upward bias inherent in the indirect own-child method relative to the direct method. As expected the magnitude of the overall bias is highest for the estimates derived from the reports of women aged 30-34, the oldest age group used in the study. The results for Zimbabwe are also consistent with findings from other studies indicating that the bias due to HIV/AIDS is greater for the under-five than the infant mortality rate. However, for Lesotho, it is difficult to infer the differential impact of the overall bias on the infant and under-five mortality rate because of the confounding effect of the relative methodological bias.

For both countries, the magnitude of the underestimation of child mortality induced by the absence of data on the survival of children of mothers who have died (selection bias) exceeds the 5 per cent threshold and is thus significant. Further research is needed to develop correction factors that adjust for the selection bias introduced by HIV/AIDS into the own-child method.

Although converting the mortality rates to a common index of mortality using a standard table which does not allow for HIV leads to the underestimation of the under-five mortality rate, the underestimation is not significant. However, there is a need for the development of model life tables that incorporate the impact of the HIV/AIDS epidemic for use in countries with a high prevalence of HIV/AIDS. Given the significant impact of the selection bias, the impact of HIV/AIDS on the own-child

method is not addressed adequately by only replacing the non-AIDS Princeton model life tables with standard life tables that incorporate the impact of the HIV/AIDS epidemic.

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1 INTRODUCTION

1.1 Background

The accurate measurement of child mortality is important because it is one of the indicators used to assess a country's level of health and development (Mathers and Boerma 2010; Hill and Amozou 2006). Vital registration systems or continuous population registers are the best source from which to estimate child mortality (IGME 2010; Ahmad, Lopez and Inoune 2000). Unfortunately, in all countries of sub-Saharan Africa vital registration is incomplete and unreliable for the accurate measurement of child mortality (Ahmad *et al.* 2000; IGME 2010).

In the absence of reliable vital registration systems, the measurement of child mortality in sub-Saharan Africa relies mostly on censuses and surveys that collect retrospective reports by women of reproductive age regarding their birth histories (Mahy 2003; IGME 2010; Hill and Amozou 2006). The own-child method is one of the techniques used to estimate child mortality indirectly from the summary birth history data collected by censuses and surveys. The method relies specifically on the retrospective reports of mothers about the survival of the children they have borne.

The epidemic of Human Immunodeficiency Virus (HIV) has compromised the accuracy of the own-child method of estimating child mortality because of the method's reliance on the retrospective reports of mothers about the survival of their children. The mortality of children whose mothers are HIV positive is higher than that of children whose mothers are negative (Mahy 2003; Ward and Zaba 2008). Thus, the estimates of child mortality derived from the own-child method are biased downwards because the mortality of children of infected mothers is under-represented at the time of the interview because of the death of the HIV positive mothers (Mahy 2003; Ward and Zaba 2008). Research is therefore needed to examine the extent of this bias, with a view towards developing a method that adjusts for the bias, should it be significant.

Unfortunately, research on the impacts of HIV/AIDS on the own-child method appears to be non-existent, in part because the few published applications of the method that are there occurred in the pre-HIV/AIDS era. At the moment, the Brass CS/CEB method is the commonly used indirect technique for estimating child mortality in developing countries (Bawah and Zuberi 1999). Thus, what little research there is on the impacts of HIV/AIDS on the indirect measurement of child mortality is focussed on the Brass CS/CEB method (Ward and Zaba 2008; Mahy 2003). There are also

concerted efforts to estimate and adjust for the bias introduced by HIV/AIDS into the direct estimates of child mortality (IGME 2010; Hallet, Gregson, Kurwa *et al.* 2010; Mahy 2003).

With HIV prevalence rates of around 24 per cent and 14 per cent respectively, Lesotho and Zimbabwe are some of the countries in Southern Africa most affected by the HIV/AIDS epidemic (UNAIDS 2010). This study evaluates the impacts of HIV/AIDS on the own-child method using the Lesotho 2009 demographic and health survey (DHS) and the Zimbabwe 1988 and 2005-6 DHS data.

1.2 Statement of the Problem

Despite the efforts to understand and address the impacts of HIV/AIDS on the estimates of child mortality from the Brass indirect method and directly using full birth history data, not much is known about its impacts on the own-child method. HIV/AIDS may well be introducing significant biases into the child mortality estimates derived using the own-child method for which adjustments need to be made.

1.3 Objectives of the study

1.3.1 Main objective

The main objective of the study is to determine the overall impact of the bias due to HIV/AIDS on the estimates produced by the own-child method, and to investigate the contribution of the various components of the overall bias. The overall bias comprises: the bias due to the selection of women who survive to be interviewed; the bias due to conversion to standard indices using a model life table; the bias due to the regression coefficients and inaccurate time location estimates; and any bias due to the method itself (relative to the direct estimates against which the estimates from the own-child method are being measured).

1.3.2 Specific objectives

The specific objectives are:

- To apply the own-child method to estimate child mortality in Lesotho and Zimbabwe, ignoring bias due to HIV;
- To determine how well MATCHTAB links children to their biological mothers in a census;
- To derive the target levels of infant and under-five mortality for Lesotho and Zimbabwe using the data on full birth histories; and
- To estimate the extent of the bias in the own-child method due to HIV/AIDS in Lesotho and Zimbabwe.

1.4 Significance of the study

The retrospective birth histories of censuses and surveys are a major source of child mortality statistics for countries like Lesotho and Zimbabwe that lack complete and reliable vital registration systems. Unfortunately, the validity of the techniques used to estimate child mortality from the birth history data, including the own-child method, is undermined by the biases introduced by HIV/AIDS into these data.

Thus, the use of the own-child method in contemporary HIV/AIDS settings calls for research that identifies the potential sources of bias in the method due to HIV/AIDS and examines the extent of this bias. This research will contribute knowledge about the overall impact of HIV/AIDS on the own-child method and the contribution of the components to the overall bias. If the extent of the bias due to HIV/AIDS on the own-child method can be identified, it might be possible for future research to find a model to adjust for the bias in the estimates.

1.5 Organisation of the dissertation

The study is organised as follows. Chapter 2 reviews the literature on the own-child method and the impact of HIV/AIDS on the methods of estimating child mortality. The chapter also reviews the mortality experience of Lesotho and Zimbabwe. Chapter 3 gives the sources of the data used in the study, and an evaluation of their quality. The chapter also presents the method used to estimate the overall bias and the component biases in the own-child method due to HIV/AIDS. Chapter 4 presents the results of applying the own-child method and the estimates of the overall and component biases in the own-child method due to HIV/AIDS. Chapter 5 discusses the results, the conclusions drawn and suggests areas of future research.

2 LITERATURE REVIEW

2.1 Introduction

This chapter reviews the theoretical concepts and application of the own-child method. The review examines the features of the method that give it a comparative advantage over other methods that rely solely on the summary birth history. The impact of HIV/AIDS on the summary birth history and full birth history methods of estimating child mortality is discussed. The research reviews some of the estimated trends of child mortality for Lesotho and Zimbabwe and the methods used to produce these trends.

2.2 Development and rationale of the own-child method

The own-child method was developed by Grabill and Cho (1965) who applied it to the United States 1960 census data to estimate age specific birth rates. Over the years, the method has been applied extensively to estimate fertility levels, differentials and trends (Zuberi and Sibanda 1999; Hoesseini-Chavoshi, Abbasi-Shavazi and Nourollahi 2009; Rindfuss 1974; Opiyo and Levin 2008). However, few researchers have exploited the potential use of the method to estimate mortality (Bawah and Zuberi 1999; Preston and Palloni 1977; Preston and Haines 1984; Opiyo 2009b; Opiyo 2009a).

The own-child method for estimating child mortality relies on summary birth history data of censuses or surveys and data regarding the age distribution of the surviving children of each woman in a household. The method entails finding the correct model life table for which the back-projected age distribution of surviving "own children" reproduces the number of children ever-born (Preston and Palloni 1977; Preston and Haines 1984).

The method is as follows. Let *B* be the total number of children ever born to reporting women and *S* and *D* be, respectively, the number of those children ever born that have survived and the number of those children ever born that have died. The total number of children born *a* years ago to reporting women is given by $B(a)$, and the number of those births *a* years ago that survive to the time of the survey is given by $S(a)$. Then, the life table probability of surviving to age *a* is given by the equation:

$$p(a) = \frac{S(a)}{B(a)}$$

Let $c_s(a)$ denote the proportion of surviving children aged *a* at the time of the survey. Then,

$$c_s(a) = \frac{S(a)}{S}$$

The ratio of the total number of children ever born to the number of those ever born who have survived (*B*/*S*), can represented by the following equation:

$$\frac{B}{S} = \frac{\int_0^{\alpha} B(a)da}{S} = \frac{\int_0^{\alpha} \frac{S(a)}{p(a)}da}{S} = \int_0^{\alpha} \frac{c_s(a)}{p(a)}da \ , \qquad (1)$$

where α is the age of the oldest surviving child born to reporting women.

Information on the total children ever born and surviving is available from a survey and the age distribution of surviving children, $c_s(a)$, can be calculated from survey information on the ages of surviving children. Thus the only unknown in the above relationship is $p(a)$.

The relationship can be solved by assuming that the $p(a)$ values belong to a one-parameter system of model life tables, for instance, the Princeton model life tables (Preston and Palloni 1977). The set of the model $p(a)$ values that satisfy equation (1) can be identified by trial and error (Preston and Palloni 1977). One way of determining the $p(a)$ values that provide the best fit to equation (1) is by linear interpolation between the identified model values (Opiyo 2009b; Opiyo 2009a).

Alternatively, the level of mortality of the model that solves equation (1) can be estimated using the Brass relational logit system (Preston and Palloni 1977). Brass proposed a two parameter linear relationship between life table survivorship probabilities of two different life tables. The Brass relational logit system is given by:

$$\text{logit}\, p(a) = \alpha_0 + \beta_0 \,\text{logit}\, p_{std}(a),$$

where $\text{logit}\, p(a) = \frac{1}{2} * \ln\left[\frac{1-p(a)}{p(a)}\right]$, $p_{std}(a)$ is the probability of surviving to age *a* in the standard life table and α_0 and β_0 are respectively, the level and shape of mortality.

The Brass two parameter logit system can be converted to a one parameter system by assuming $\beta_0 = 1$. Brass's relational logit system can then be written with $\beta_0 = 1$ as:

$$\frac{1}{2} * \ln\left[\frac{1 - p(a)}{p(a)}\right] = \alpha_0 + \frac{1}{2} * \ln\left[\frac{1 - p_{std}(a)}{p_{std}(a)}\right]$$

From which: $\frac{1}{p(a)} = \frac{\exp^{2\alpha_0}}{p_{std}(a)} - \exp^{2\alpha_0} + 1$

This expression for $\frac{1}{p(a)}$ can be substituted into equation (1) to give:

$$\frac{B}{S} = \int_0^{\alpha} c_s(a) * \left[\frac{\exp^{2\alpha_0}}{p_{std}(a)} - \exp^{2\alpha_0} + 1\right] da$$

Expanding the terms in the integral and noting that $\int_0^{\alpha} c_s(a) da = 1$, the above equation reduces to:

$$\frac{B}{S} = \exp^{2\alpha_0} * \int_0^{\alpha} \frac{c_s(a)}{p_{std}(a)} da - \exp^{2\alpha_0} + 1$$

To solve for α_0, the level of mortality, the above equation is rearranged and $S + D$ can be substituted for *B* to give:

$$\frac{D}{S} = \exp^{2\alpha_0} * \left[\int_0^{\alpha} \frac{c_s(a)}{p_{std}(a)} da - 1\right],$$

which simplifies to: $\alpha_0 = \frac{\ln D - \ln S - \ln[M - 1]}{2}$,

where *M* is the trial sum of $\int_0^{\alpha} \frac{c_s(a)}{p_{std}(a)} da$

Thus, the set of $p(a)$ values can be identified for this level. Where necessary, the $p(a)$ values are estimated by linear interpolation between tabulated values of $p(a)$.

2.3 Linking surviving children within a household to their biological mothers

Application of the own-child method starts with the matching of women at ages between 15 and 64 in each household to their biological children aged below 15 years, either manually or using matching software, such as MATCHTAB. The matching procedure uses the variable for the household identifier and information derived from responses to the survey questions on age, sex and relationship to the head of household

(Higa, Ho, Shima and Lee 1985). Matching using MATCHTAB begins with the software which scans each household and identifies each woman aged between 15 and 64 as a potential mother and each child aged below 15 years as a potential child (Higa *et al.* 1985). According to the order in which women are listed in the household schedule, the software uses either the relationship to the head of household code or the mother's line number to link the first potential mother to a child whose age tallies with the potential mother's reproductive lifespan (Higa *et al.* 1985). Auxiliary MATCHTAB input data for each woman containing information regarding the number of children she has ever borne and the number of children living at home is used by the software to provide a check on the maximum number of children that can be linked to a woman (Higa *et al.* 1985). MATCHTAB stops allocating own-children to a potential mother when the number of children matched to her equal the number of her children living at home or when the software has scanned all un-matched children in the household (Higa *et al.* 1985). If there is more than one potential mother in a household, again, the software uses the order in which women are listed in the household schedule to scan for the next potential mother. If this other potential mother is neither the household head nor the spouse of the household head, the software sifts through the relationship to the head of household codes or uses the mother's line number to link the potential mother to each un-matched child whose age tallies with the potential mother's reproductive lifespan. Allocation of own-children to the potential mother stops when her matched children equal her children living at home or when the software has scanned all un-matched children in the household. This procedure of allocating own-children is repeated for all potential mothers in a household. There is a possibility of misallocating children to non-biological mothers in complex households where either a potential mother is another spouse of the household head or potential children are step children of either the household head or the spouse. Nonetheless, the use of MATCHTAB to link surviving children within a household to their biological mothers is still helpful to the application of the own-child method.

2.4 Application of the own-child method to estimate infant and child mortality

The estimation of childhood mortality using the own-child method entails applying either the fundamental equation (1) as described in section 2.2, or the approach proposed by Preston and Palloni (1977). Both versions of the own-child method require data on the number of children ever born to each reporting woman and the number of

those children ever born that have survived. The application of the approach proposed by Preston and Palloni (1977), specifically requires the stratification of these data by five-year age groups of women. In addition, the application of both versions of the method used in this research requires the number of surviving own-children in the age range 1-15 years nearest birthday of women at ages between 15 and 34 years.

The application of either version of the own-child method assumes that mortality of children is independent of their mother's. It is also assumed that the mortality of children in the populations studied can be described by given model life tables (Preston and Palloni 1977). The application of the fundamental equation of the own-child method uses these model life tables to identify the set of the model $p(a)$ values that satisfy equation (1). The approach proposed by Preston and Palloni (1977) relies on a model life table for the conversion of the proportions of children dead by age group of mother into probabilities of dying. The model life table is also the basis for the regression coefficients that are used to calculate the time location of the estimates of childhood mortality. The same model life table is also used to convert the estimates of childhood mortality to a standard index of mortality, q_0, or ${}_5q_0$. Further, the calculation of the time location estimates assumes that the rate of mortality change is constant over time. In addition, the following implicit assumptions are made when applying either version of the own-child method: that ages of children and women are accurately reported; all children live in the same household as their mothers; and census coverage of women and children is complete (Rindfuss 1974).

The first stage in the estimation of childhood mortality using the method by Preston and Palloni (1977) requires the calculation of the number of children ever-born to reporting women in age group *i*, $B(i)$, and the number of those children ever borne that survive to the time of the interview, $S(i)$, where *i*=1 refers to the 15-19 age group, 2 refers to the 20-24 age group, . . ., 4 to the 30-34 age group. The number of children dead reported by women in age group *i*, $D(i)$, is then calculated as the difference between the number of children ever born and the number of children surviving. The proportion of children dead is calculated for each age group of women by dividing the number of children dead by the number of children ever born to women in the age group.

The mean age nearest birthday of surviving children of reporting women in age group *i*, $A_s(i)$, and the proportion of the surviving children of women in the age group

who are aged under 3 nearest birthday, $c_2(i)$, is then computed using the tabulation of surviving children aged 1-15 years nearest birthday by the child's age in single years, and five year age groups of mothers.

For the age group of women *i*, the multiplier $k(i) = \alpha(i) + \beta(i).A_s(i) + \delta(i).c_2(i)$ is calculated using the coefficients $\alpha(i)$, $\beta(i)$, and $\delta(i)$ produced by Preston and Palloni (1977). The coefficients were derived using regression analysis of simulations of fertility and child mortality histories based, on Princeton model life tables.

The probability of dying by age *a*, $q(a)$, is estimated for each of the age groups of women as the product of the proportion of children dead for women in the age group and the multiplier for that age group. These $q(a)$ values correspond closely to the child ages 1, 2, 3 and 5 for the four, five-year age groups of women in the age range 15-34.

Assuming that the rate of mortality change is constant over time, the number of years before the survey, $T_0(i)$, that these estimates of $q(a)$, apply is estimated using the equation $T_0(i) = \alpha(i) + \beta(i).A_s(i)$, where $A_s(i)$ is as previously defined and $\alpha(i)$, and $\beta(i)$ are regression coefficients derived by Palloni (1980). The table of coefficients for the West family of the Princeton model life tables is presented in Palloni (1980). Although the coefficients for the other families of the Princeton model life tables are different from those of the West family, they produce approximately similar predicted values of $T_0(i)$ (Palloni 1980). The date to which each mortality measure, $q(a)$, applies is estimated by subtracting $T_0(i)$ from the survey date.

Afterwards, the $q(a)$ values are converted to common indices of mortality, q_0, and ${}_5q_0$. The conversion is done using the Princeton model life tables as the standard tables in the Brass logit relational model with $\beta = 1$, to determine the implied infant and under-five mortality measures.

2.5 Comparative strengths and weaknesses of the own-child method over the summary birth history method

The Brass CEB/CS technique for estimating child mortality, based solely on the summary birth history data assumes that fertility has remained constant in the recent past. In contrast, the own-child method which relies on the age distribution of surviving children in addition to the summary birth history does not require this assumption of constant fertility, because any changes in fertility are reflected in the age distribution of

surviving own-children, i.e. the $c_s(a)$ function (Preston and Palloni 1977; Preston and Haines 1984). The own-child method is expected to be better suited for Lesotho and Zimbabwe where fertility is declining (CSO and Macro International 2007; MoHSW and ICF Macro 2010), than techniques based solely on summary birth history data. Given that the estimates of childhood mortality derived using the own-child method are anticipated to be more accurate than those derived using the Brass CEB/CS method during periods of fertility change, this research focuses on the former technique instead of the latter. Furthermore, by applying the own-child method, this research seeks to take advantage of the opportunity to validate the internal consistency of the estimates of childhood mortality provided by the use of both variants of the method.

The estimate of the infant mortality rate derived using the fundamental equation of the own-child method is based on the reports of all women and is thus better in comparison to the equivalent estimate from the Brass technique (Preston and Palloni 1977). The Brass estimate of infant mortality is biased upwards because it relies on the reports of young women aged 15-19 whose children usually experience increased mortality risks (Hill 1991; United Nations 1983; Hill and Figueroa 2001). In addition, the Brass estimate of infant mortality is unreliable because of the relatively small number of children ever born and children dead reported by women aged 15-19 years (United Nations 1983; Hill 1991; Hill and Figueroa 2001). For this reason, applications of this method usually exclude estimates based on the reports of these women.

The application of the fundamental equation of the own-child method provides the flexibility to express information by any age group of women, wider than the usual five-year age groups. For instance, the fundamental equation of the method is applied in this research based on the reports of women between the ages 15 and 34 years. This is an advantage for the method because such broad age groups can be conveniently used to counter problems related to small samples and produce better estimates of childhood mortality, besides the infant mortality rate (Preston and Palloni 1977; Preston and Haines 1984).

In spite of the aforementioned strengths, the own-child method of estimating childhood mortality has some shortcomings. The method is sensitive to errors in the reporting of the ages of children and women. Age misreporting distorts the proportionate age distribution of the surviving children, i.e. the $c_s(a)$ values. This undermines the accuracy of the estimates of childhood mortality derived using the method. The own-child method is applied after linking children enumerated in each

household to their biological mothers. If the method is applied to censuses and surveys that do not provide a direct mother-child link, the link is inferred indirectly from information on the relationship to head of household or the mother's line number. Thus, algorithms are required to ensure the matching of a child and a potential mother and their ages are compatible. The application of the own-child method is therefore compromised by the possibility of misallocating children to non-biological mothers. The likelihood of this occurring is high in complex households where either a potential mother is another spouse of the household head or potential children are step children of either the household head or the spouse. The application of the own-child method is also compromised by the migration of children in-and out-of households. In countries with a high prevalence of HIV/AIDS, a significant proportion of orphaned children is adopted by relatives who often report them as their own children. The erroneous reporting of adopted children as biological children induces a downward bias into the estimates of childhood mortality.

2.6 Impact of HIV/AIDS on the own-child method

There is a paucity of research on the impacts of HIV/AIDS on the own-child method, presumably because most of the few applications of the method appear to have been confined to the pre-HIV/AIDS era. Opiyo (2009a) alludes to the bias induced by HIV/AIDS on the own-child method of estimating child mortality resulting from the correlation between child and maternal mortality. He identifies the use of Princeton model life tables in high HIV/AIDS prevalence settings where the age pattern of mortality does not conform to these standard models as a source of bias. Opiyo (2009a) applies the own-child method to data for four Kenyan censuses and, other than mentioning that the estimates of child mortality were adjusted for the impact of HIV/AIDS using INDEPTH model life tables, he does not address the impact of bias due to HIV/AIDS on the method. To fill this apparent gap in knowledge, this research identifies most of the potential sources of bias in the own-child method due to HIV/AIDS and examines the extent of this bias.

The own-child method requires linking surviving children within a household to their biological mothers using information recorded on the survey household schedule. In an HIV/AIDS context, child mortality estimates derived from a process that links only surviving mothers to their surviving own-children are biased downwards because HIV infected mothers and their children experience increased mortality and are under-represented at the time of the survey.

Furthermore, the own-child method is distorted by migration of children in and out of households. This is a potential source of error in Lesotho and Zimbabwe where, due to the high HIV/AIDS prevalence of 23.6 per cent and 14.3 per cent, respectively (UNAIDS 2010), a significant proportion of orphaned children is adopted by relatives who may report them as their own children. If children are misallocated to non-biological mothers, the reported number of surviving children is higher than the actual number surviving which would bias the estimates of childhood mortality downwards.

Since the own-child method assumes that the mortality of children is independent of that of their mothers, and the adult HIV prevalence rates for Lesotho and Zimbabwe are relatively high, the assumption that the dependence of maternal and child mortality has an insignificant effect does not hold. In HIV affected countries such as Lesotho and Zimbabwe, maternal and child mortality are correlated due to vertical transmission of HIV and the "…indirect increase in child mortality if the mother is sick or has died" (Mahy 2003:3). This correlation results in an upward bias in reported child survival because the mortality of children whose mothers are HIV positive is higher than that of children whose mothers are negative (Ward and Zaba 2008; Mahy 2003). Thus, the mortality of children of infected mothers is under-represented at the time of the survey because of death of their HIV positive mothers (Hallet *et al.* 2010).

The own-child method assumes the mortality of children can be described by standard model life tables, for instance, the Princeton model life tables (Mahy 2003). Clearly, the Princeton model life tables that were constructed during the pre-HIV/AIDS era do not take HIV/AIDS into account. In HIV/AIDS contexts, excess child mortality due to HIV/AIDS is not reflected by these model life tables. The Princeton model life tables are inappropriate in an HIV setting, such as Lesotho and Zimbabwe, where the age pattern of mortality does not conform to these 'standard' model life tables because of HIV/AIDS.

The calculation of time locations is based on the assumption that the rate of mortality change is constant over time. Changes in the shape of the mortality curve induced by HIV renders the estimates of time location inaccurate because the assumption of a constant change in mortality over time is violated and the model life tables used in deriving the estimates of time location is not appropriate (Ward and Zaba 2008). In addition, the coefficients for calculating the time locations were derived from simulations that did not consider HIV/AIDS.

These sources of bias are expected to result in errors of different magnitudes. The significance of the errors resulting from each potential source of bias needs to be evaluated with a view to informing the extent to which results from this research can be generalised.

2.7 The impact of HIV/AIDS on the estimation of child mortality using summary birth history data

The Brass children ever born children surviving method is the most widely used indirect technique for estimating childhood mortality in developing countries (Hill and Figueroa 2001). The method converts the proportions of children dead among children ever born to women in the age groups 15-19, 20-24, . . ., 45-49 to life table probabilities of dying between birth and exact age a $q(a)$, based on the past fertility pattern of the female respondents (United Nations 1983; Hill 1991). Application of the Brass method is based on the following assumptions: that mortality of children is independent of their mother's; the mortality of children does not depend on their mother's age; the mortality of children in the populations being studied can be described by given model life tables; childhood mortality has been constant in the recent past; and that fertility of the female respondents has remained constant in the recent past (United Nations 1983; Mahy 2003; Hill 1991; Ward and Zaba 2008).

Some of the assumptions required to apply the Brass method are similar to the assumptions required to apply the own-child method. For instance, the assumption that the mortality of children is independent of that of their mothers and the mortality of children in the populations being studied can be described by given model life tables. To calculate the number of years before the census or survey to which the estimates of childhood mortality refer, a variation of the Brass method also assumes that child mortality has been changing linearly in the past. Thus, these assumptions are similarly violated in HIV/AIDS contexts.

In high HIV prevalence settings of Lesotho and Zimbabwe, maternal and child mortality are significantly correlated due to vertical transmission of HIV from mother to child and an increase in child and adult AIDS mortality (Ward and Zaba 2008; Mahy 2003). Since the Brass method is based on the reports of women who survive to the time of the survey, births and deaths of children of HIV positive mothers are under reported because of the high mortality of their mothers. This results in a downward bias of the child mortality estimates because mortality of children whose mothers are HIV

positive is higher than that of children whose mothers are negative (Ward and Zaba 2008; Mahy 2003; Ahmad *et al.* 2000).

Child mortality is also not independent of the mother's age in the context of HIV because HIV is age dependent (Ward and Zaba 2008). Therefore, in high HIV prevalence situations such as Lesotho and Zimbabwe, the assumption that the mortality of children is independent of their mother's age is also violated.

The assumption that the mortality of children in the populations being studied can be represented by chosen life tables, for instance, the Princeton or United Nations model life tables is violated because these model life tables were constructed from HIV-free data. The model life tables are inappropriate in HIV settings because they do not reflect excess child mortality due to HIV/AIDS and the age pattern of mortality in HIV settings is different from these model life tables (Ward and Zaba 2008; Mahy 2003).

HIV also renders the time location estimates inaccurate because the assumption of a linear change in mortality is violated. In addition, the coefficients for calculating the time location estimates were derived from model life tables that were constructed without taking account of HIV/AIDS (Ward and Zaba 2008).

Assuming a stable population and stable HIV epidemic, Ward and Zaba (2008) examine the extent of the errors introduced by HIV in the estimates of child mortality derived using the Brass technique. They defined the factors, $n(z)$, required to correct the estimates of child mortality, $q(z)^e$, derived from the usual application of the Brass technique for the errors introduced by HIV as the difference between these estimated $q(z)^e$ values and the true level of mortality, $q(z)^t$. Thus, the true estimate of child mortality $q(z)^t$, corrected for the bias introduced by HIV is given by:

$$q(z)^t = q(z)^e + n(z)$$

To estimate the correction factors, $n(z)$, two regression models were used, a basic model and an extension of the basic regression model with one additional variable selected by a stepwise regression procedure. The basic regression model used is given by:

$$n(z) = aPREV + b(PREV)^2,$$

where *PREV* is the prevalence of women in the age range 15 to 49, expressed as a proportion. The regression coefficients for the basic model were all significant at the one per cent level of significance except the *b* coefficient of the 15-19 age group. The extended regression model is as follows:

$$n(z) = aPREV + b(PREV)^2 + cPREV15,$$

where *PREV15* is the prevalence of women aged 15-19, expressed as a proportion. The regression coefficients of the extended model were all significant at the one per cent level of significance and these coefficients provided improved estimates for the youngest age groups compared to the basic regression model.

The predicted $n(z)$ values were then used to determine the maximum HIV prevalence rates at which errors in the estimates fall within the 5 per cent range for the seven five-year age groups of women in the age range 15 to 49. Ward and Zaba found that the normal application of the Brass technique produces errors outside the acceptable range of 5 per cent if the prevalence exceeds 4 per cent. Errors in the estimates from the normal application of the Brass technique derived from reports of women in the age groups 40-44 and 45-49 fall outside the 5 per cent range even at prevalence rates that are lower than 4 per cent. Ward and Zaba also found that for both the basic and extended models, the error in the estimate of ${}_5q_0$ derived from reports of women aged 30-34 falls within the 5 per cent range even if prevalence is as high as 45 per cent. The estimates for the extended model are accurate even if prevalence rates are above 30 per cent for all age groups except the 40-44 and 45-45 age groups. The basic model produces reliable estimates for prevalence rates above 30 per cent for the age groups 25-29, 30-34 and 35-39. For the first, second and sixth age groups, the basic model produces reliable estimates for prevalence rates up to 12 per cent and up to 3 per cent for the seventh age group. Based on these observations, Ward and Zaba (2008:56) conclude that the extended model "... increases the prevalence at which accurate estimates can be made".

The work by Ward and Zaba indicates that constant HIV introduces significant error into the estimates derived from the normal application of the Brass technique, even for prevalence levels that are below 5 per cent. They derived the correction factors, $n(z)$, to adjust for these errors by assuming a stable population and HIV epidemic. In the case of Lesotho and Zimbabwe, incidence and prevalence have not been constant over time. Ward and Zaba concede that further research is required to determine the effects of the changes in the incidence of HIV over time. At the moment, the correction factors by Ward and Zaba provide the only method for adjusting the child mortality estimates derived from the Brass technique for errors introduced by HIV.

2.8 Impact of HIV/AIDS on the estimation of child mortality using full birth history data

The direct estimation of child mortality from birth histories entails collecting full birth histories from women in the reproductive age range 15-49 years (Mahy 2003). For each woman, the birth history collects information regarding the date of birth and survival status of every child and the dates of death or ages at death for those children who have died (Rutstein and Guillermo 2003; IGME 2010). The direct method, like the indirect methods of estimating child mortality also assumes that the mortality of children is independent of that of their mother's (Mahy 2003). In high HIV prevalence settings, child mortality estimates derived from full birth histories of women are biased downwards because the mortality of mothers is correlated with their children's mortality (Hallet *et al.* 2010).

Hallet *et al.* (2010) estimate the extent and temporal variation of the underestimation introduced by HIV into the estimates of infant and under-five mortality rates derived from full birth histories for Manicaland province in Zimbabwe. They estimate the bias using an empirical investigation and a mathematical simulation model. The former approach estimated the extent of underestimation for the survey period 1998-2005 while the latter approach explored the variation of the bias during the course of the HIV epidemic. The prospective study by Hallet *et al.* (2010) collected birth history data from women in the reproductive age range 15-49 years, in three survey rounds from the same sites that were selected for the baseline study. Birth history reports of women who died since a previous survey round were collected by verbal autopsy interviews conducted with their caregivers.

The empirical investigation produced two sets of direct estimates of infant and under-five mortality rates that were calculated using the synthetic cohort life table approach. The first set estimated infant and under-five mortality using birth history data from the third survey round based on the reports of surviving mothers. The second consisted of estimates of infant and under-five mortality rates for children of deceased mothers based on verbal autopsy data from the second and third survey rounds. Corrected infant and under-five mortality rates for all mothers, surviving and deceased, were estimated by combining the two sets of estimates with weighted adjustments made for the unequal selection probabilities of the cohort members and the loss to follow up of cohort members who had died. The latter adjustment assumed that women who had died between survey rounds are lost to follow up at the same rate as the surviving women. Hallet *et al.* (2010) estimated the extent of the underestimation as the difference

between the corrected estimates of infant and under-five mortality rates for all mothers and the estimates derived from reports of surviving mothers as a per cent. The empirical investigation shows that the extent to which the true level of mortality was underestimated was greater for under-five (9.8 per cent) than infant mortality (6.7 per cent) because of the increased likelihood of death before the interview of women with births further back in time. Given that the extent of the underestimation of both infant and under-five mortality exceeds 5 per cent, the authors conclude that this provides empirical evidence that the bias is significant and there is a need to correct estimates from retrospective birth histories for this bias.

The mathematical model produced three sets of infant and under-five mortality rates. The first, which the authors termed the uncorrected "DHS analogue", are direct estimates of infant and under-five mortality rates for the periods 0-4, 5-9 and 10-14 years before the survey that were calculated using the synthetic cohort life table approach used in the demographic and health survey computation. The DHS analogue estimates are solely based on the simulated model data for surviving mothers. The model results from the DHS analogue were calibrated to match national estimates from the 1988, 1994, 1999 and 2005-06 Demographic and Health Surveys closely. The second, the "DHS continuous", are a continuous time series of infant and under-five mortality rates calculated in the same manner as the DHS analogue estimates but without censoring of child survival times. The third, the "corrected" estimates, are a time series of infant and under-five mortality rates that are calculated in the same manner as the DHS continuous estimates with additional simulated data for women who died of AIDS before the survey. The authors estimated the extent of the underestimation of infant and under-five mortality rates during the course of the HIV epidemic as the difference between the DHS continuous and the corrected time series of estimates. The model results show that from 1990, the corrected time series is greater than the DHS analogue, and the DHS continuous, indicating underestimation of infant and under-five mortality rates due to HIV as measured by the gap between the first and the third series of estimates. The extent of this bias increases during the course of the HIV epidemic with significant biases that exceed five per cent becoming manifest by the late 1990s. Using the model, the authors predict that for the period 2005 to 2009, infant and under-five mortality rates are underestimated by 9 per cent and 13 per cent respectively. Similar to the empirical results, model results indicate that the extent of the errors is greater for under-five than infant mortality. The model estimates of the bias for

the period 1998-2005 of 7.1 per cent and 9.7 per cent for infant and under-five mortality respectively are consistent with the empirical results for the same period, possibly because the model is calibrated using national estimates from the 1988, 1994, 1999 and 2005-06 Demographic and Health Surveys.

The United Nations Inter-agency Group for child mortality estimation, IGME (2010), a grouping of experts from UNICEF, the World Bank, the World Health Organisation (WHO), the United Nations Population Division and academia, developed a method to estimate and adjust for the bias of HIV in the estimate of the under-five mortality rate derived from full birth history data because of their sole reliance on reports of mothers who survive to the time of the survey. The input required for estimating bias are a SPECTRUM projection of the country's annual number of births and the annual HIV prevalence among pregnant women in the age range 15-49. The following input data are also required: an assumed mother-to-child HIV transmission rate of 35 per cent; and the West family of the Princeton model life tables with the level of the under-five mortality rate chosen to be approximately equal to that of the HIV negative population. The method for estimating the bias also requires an associated single decrement life table, excluding deaths due to non-AIDS causes of the HIV positive births for ages zero up to five that is fitted on the basis of evidence from cohort studies which indicate that 62.5 per cent of HIV positive births die by the age of five. Further, the method uses a survival function from four years after infection with HIV to the year of any given survey that is generated from a survival function from first infection of females with a median survival time of 9.5 years.

For each of the years before a given survey, the HIV prevalence among pregnant women in the year of birth is used to apportion the births to HIV positive and HIV negative women. The IGME (2010) assumes that all of the births to HIV negative women are HIV negative. The assumed mother-to-child HIV transmission rate of 35 per cent is used to subdivide the births to HIV positive women by HIV status. Thus, for any given year before the survey, there are three categories of births. These are HIV negative births that are born to HIV negative mothers, HIV negative births that are born to HIV positive mothers, and HIV positive births that are born to HIV positive mothers.

The deaths that occur before the age of five during any given year before a survey to the HIV negative births that are born to HIV negative and HIV positive mothers are then calculated using the age-specific mortality rates from the West family of the

Princeton model life table. The calculation of the deaths that occur to these two categories of births assumes that HIV negative children experience the same mortality risks notwithstanding the HIV status of the mother. The deaths of the children who are HIV positive that occur before the age of five during any given year before a survey is calculated using the age-specific mortality rates from the associated single decrement life table for HIV positive births.

The IGME (2010) assumes that all of the women who are HIV negative survive to report all of their births and the deaths of their children who die before the age of five. To estimate the number of births and deaths to children below the age of five that are unreported in a survey because of the deaths of HIV positive mothers, the IGME (2010) formulate two additional assumptions. First, it is assumed that the births to HIV positive mothers occur on average to the mothers four years after infection. The IGME (2010) justifies the choice of four years by stating that the fertility of HIV positive women drops by almost a quarter after a period of four years of infection with HIV. The IGME (2010) also assumes that surveys are conducted at the end of the calendar year. Based on these assumptions, the number of births and deaths before the age of five of both HIV negative and HIV positive children born to HIV positive mothers reported in a survey is then calculated using the conditional probability that an HIV positive woman, infected for four years at the birth of her child, survives from the time of birth to the time of a survey. Thus, births and under-five deaths reported in a survey comprise of the reported births and under-five deaths of children born to HIV positive mothers and the births and the under-five deaths of children born to HIV negative mothers. The births and the under-five deaths of HIV negative and HIV positive children born to HIV positive mothers that are not reported in a survey are calculated using the conditional probability that an HIV positive woman infected for four years at the birth of her child, dies between the time of birth and the time of a survey.

The IGME (2010) calculates the true number of births and under-five deaths as the sum of the births and deaths that are reported by both HIV positive and HIV negative mothers and those that are unreported by HIV positive mothers. These true births and under-five deaths and the births and under-five deaths reported by both HIV positive and HIV negative mothers are summed for each of the three five-year periods, 0-4, 5-9 and 10-14 years prior to a survey. The extent of the bias in the estimate of the under-five mortality rate for any given five-year period preceding a survey is estimated as the ratio of the reported under-five deaths to the reported births divided by the ratio

of the true under-five deaths to the true births. Thus, the adjusted estimate of the under-five mortality rate is obtained by dividing the survey estimate for a given five-year period preceding a survey by the bias for the corresponding period.

2.9 Comparison of the bias due to HIV/AIDS on direct and indirect child mortality estimates

The impact of HIV/AIDS on the direct methods of estimating child mortality has been found to be different and lower than for the indirect methods. Although both methods of estimating child mortality rely on the assumption that the mortality of children is independent of that of their mothers, estimating child mortality using the direct methods does not rely on the mother's age group (Mahy 2003). In addition, the direct methods do not require the use of model life tables, of which the commonly used Princeton and United Nations model life tables, were constructed from HIV-free data. The bias introduced by HIV/AIDS is thus different when direct methods are used to estimate child mortality compared to indirect methods because more assumptions of the indirect methods are violated in contrast to one for the direct methods (Mahy 2003).

2.10 Recent estimates of child mortality in Lesotho and Zimbabwe

Different groups and individual researchers have produced estimates of trends of infant and under-five mortality rates for Lesotho and Zimbabwe using different methods of estimation and different data sources. This research reviews the estimated trends of infant and under-five mortality rates for Lesotho and Zimbabwe, the methods used to produce the trends and possible explanations for these estimated trends.

The IGME (2007) and Hill and Amozou (2006) produce estimated trends of the infant and under-five mortality rate using direct and indirect estimates derived from vital registration data, as well as full and summary birth history data of nationally representative surveys and censuses. For countries with a low prevalence of HIV/AIDS, a weighted least squares regression with linear splines and knots is fitted independently to the relationship between the logarithm of the infant or under-five mortality rate and the reference date for each estimate. The series of the under-five mortality rates derived mainly from summary and full birth history data is considered the better series than the series of the infant mortality rates. This is because the accuracy of the indirect estimate of the infant mortality rate derived from the summary birth history depends on the model life table used in the estimation procedure. Likewise, the accuracy of the direct estimate of the infant mortality rate derived from the full birth history is compromised

by the problem of the heaping of deaths at age one. Thus, for countries that rely mostly on the summary and full birth history data for the measurement of child mortality, the logarithm of the under-five mortality rate is used as the dependent variable. On the other hand, the logarithm of the infant mortality rate is used as the dependent variable for countries with complete vital registration systems because these provide better estimates of the infant mortality rate than of the under-five mortality rate.

The estimates of the infant or the under-five mortality rate are weighted based on a prior evaluation of the quality of the data source. Direct and indirect estimates derived from a single survey or census that collects full or summary birth history data are assigned a combined weight of five. In countries where vital registration is complete, Hill and Amozou (2006) and the IGME (2007) assign a weight of 1 and 1.25 respectively to each annual estimate derived from vital registration data. Knots are located going back in time from the latest estimates of the infant or under-five mortality rate. A knot is defined each time the sum of weights of successive estimates is a multiple of five. However, the first knot, that is, the earliest knot going back in time is defined such that the sum of the remaining weights is at least five.

To fit the model relating the infant or under-five mortality rate and the reference date for each estimate, linear splines are used based on the assumption that the rate of change of infant or under-five mortality is constant between knots but changes at each knot. The model is given by the equation:

$$\ln({}_nq_0)_i = b_0 + b_1(date)_i + b_2(postk1)_i + b_3(postk2)_i + b_4(postk3)_i + ... + e_i,$$

where the dependent variable is the logarithm of the infant or the under-five mortality rate. The variable *date* is the calendar year. The independent variables *postk1* and *postk2* are defined respectively as the variable *date* minus the date of the earliest knot if positive, or zero otherwise and *date* minus the date of the second earliest knot if positive, or zero otherwise. The independent variables *postk3*, *postk4* and so on, are defined in a similar manner. The regression coefficients, b_k, (for k=2, 3, 4, . . .) reflect the changes in the rate of change of infant or under-five mortality in a given period. The error terms, the e_i values, are assumed to be independent and normally distributed around the logarithm of either the infant mortality rate or the under-five mortality rate with a mean of zero and a constant variance, δ^2.

The regression equation is used to fit independently a smooth trend of infant or under-five mortality rates and to extrapolate the trend forward or backward to produce

estimates for any desired date. For countries such as Lesotho and Zimbabwe with incomplete vital registration systems, the series of under-five mortality rates derived mainly from summary and full birth history data is considered the better series and is thus chosen as the base. The series of implied infant mortality rates is then derived from the series of under-five mortality rates using Princeton model life tables.

The IGME (2010) derive estimated trends of infant and under-five mortality rates for countries with a high prevalence of HIV, including Lesotho and Zimbabwe, by fitting a weighted Loess regression of the under-five mortality rates over time. The IGME (2010) has developed a method that can only estimate and adjust for the bias in the direct estimates of the under-five mortality rate derived from full birth history data due to HIV. The description of the method is provided in section 2.8. Thus, to estimate trends of infant and under-five mortality rates, the direct estimates of the under-five mortality rate with reference dates within the periods that are affected by the HIV epidemic, are first adjusted for the selection bias of HIV. For each of these time points within the HIV epidemic period, the non-AIDS under-five mortality rate is calculated by removing the UNAIDS model estimate of AIDS under-five mortality from the estimate of the under-five mortality rate. A Loess regression model is then used to fit local regressions to the relationship between the log of the non-AIDS under-five mortality rate and the reference date for each estimate. The fitted Loess regression equation is then used to extrapolate the trend of the non-AIDS under-five mortality rate forward or backward and produce estimates up to the year 2009. For each country, the range of values used to fit each local regression, alpha, is calculated as the ratio:

$$5 / (\text{number of independent data series in the country})$$

If the value of alpha is large, the trend of estimates for all local regressions is smoothest and is more likely to be sustained in the long term. To capture large changes in child mortality anticipated to be occurring over short time periods in Zimbabwe, a smaller value of alpha, calculated as:

$$5 / (3 + \text{the number of independent data series in the country})$$

is considered.

For time points within the epidemic period, the estimate of the under-five mortality rate is then obtained by adding back the UNAIDS model estimate of AIDS under-five mortality to the non-AIDS under-five mortality rate extrapolated using the fitted regression model. The trend of the under-five mortality rate is inferred from the Loess fit of all points of estimation. The estimate of the implied non-AIDS infant

mortality rate for each time point within the epidemic period is derived from the estimated non-AIDS under-five mortality rate using Princeton model life tables. The infant mortality rate is then calculated by adding UNAIDS model estimates of AIDS infant mortality to the estimate of non-AIDS infant mortality rate.

The UNAIDS model estimates of AIDS infant and under-five mortality rates are produced using the Spectrum projection package developed jointly by the Futures Group, UNAIDS, WHO and UNICEF. A non-AIDS demographic projection is first prepared using DemProj, a demographic projection model of SPECTRUM (Stover and Kirmeyer 2008; Stover 2009). DemProj produces a cohort component projection based on the following input data; the base year population by age and sex, the age pattern of fertility, the age pattern of mortality, and for each year, the total fertility rate (TFR), the non-AIDS life expectancy at birth and the age and sex distribution of international migrants (Stover and Kirmeyer 2008; Stover 2004). HIV/AIDS is incorporated into the demographic projection using a module of SPECTRUM called AIM that requires assumptions about the characteristics of the HIV epidemic and data regarding the treatment coverage and utilization of PMTCT services (Stover 2009). The assumptions relate in part to the sex ratio of incidence, the age pattern of incidence, the distribution of the time from infection to AIDS death for both adults and children, the effect of HIV on fertility, and the probability of transmission of HIV from mother to child (Stover 2009). A projection of the national adult prevalence and incidence over time, prepared in the Estimation and Projection Package (EPP) model using HIV sentinel surveillance data and data from national population based surveys, for countries that have collected such data or in Workbook for countries with low level and concentrated epidemics that lack surveillance data for high risk population groups is also used as input data into AIM (Stover 2004). HIV/AIDS is incorporated into the demographic projection through the AIDS deaths projected by AIM and the impact of HIV on fertility specified in the AIM model (Stover 2009). A time series of AIDS infant and under-five mortality rates is a part of the output from the SPECTRUM projection that is prepared using the AIM module.

For developing countries such as Lesotho and Zimbabwe, Ahmad *et al.* (2000) derived trends in under-five mortality rates based on data from the World Fertility Survey and Demographic and Health Survey programs. They derived a series of estimates of the under-five mortality rate by evaluating the quality and plausibility of estimates and then calculating under-five mortality estimates for five-year periods using

un-weighted averages of the plausible estimates. The authors concede that a shortcoming of their approach is that it estimates trends based on unequal numbers of data points for different five-year periods.

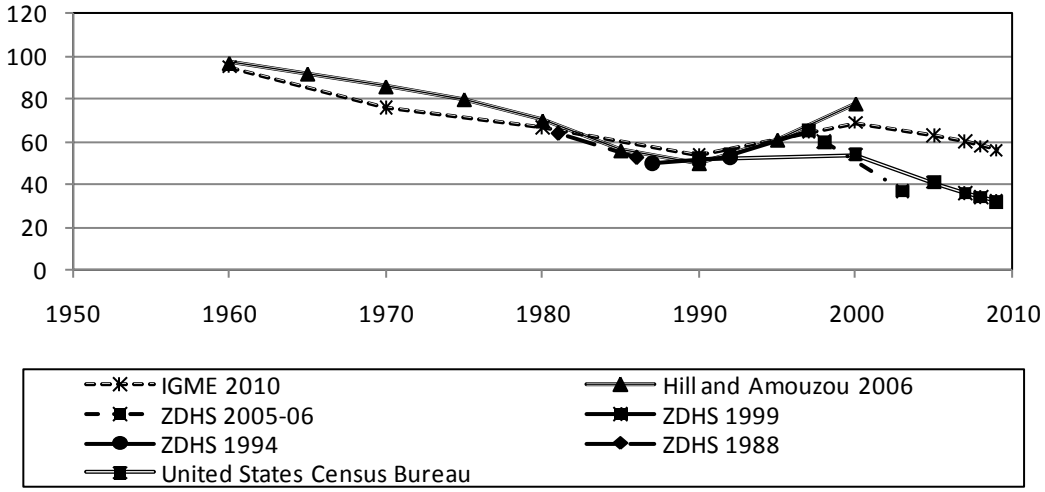
The trends in estimates of infant and under-five mortality rates for Zimbabwe produced by these researchers together with the trends inferred from two successive five-year periods preceding the 1988, 1994, 1999 and 2005-06 Zimbabwe Demographic and Health Surveys (ZDHS), as well as trends produced by the United States Census Bureau (2011) are shown in Figure 2.1 and Figure 2.2.

Among other factors, the HIV epidemic contributes most to the recent trends of infant and under-five mortality. Consequently, trends are presented for the pre-epidemic period, the decade when the HIV/AIDS epidemic first exerted a significant impact on childhood mortality, and the period after the first decade of the epidemic. Given that in developing countries, most infants who acquire HIV infection from their mothers die by the age of five (Adetunji 2000), the impact of HIV infection on childhood mortality should lag by at least five years. In Zimbabwe, the first case of HIV was reported in 1985 (USAID 2010b). Thus, the period around 1990 to 2000 is expected to be the decade when HIV/AIDS first exerted a significant impact on childhood mortality in Zimbabwe.

The trends of infant and under-five mortality rates inferred from the 1988, 1994 and 1999 Zimbabwe Demographic and Health Surveys are consistent for overlapping periods and are also consistent with the estimates from the other sources. Child mortality estimates derived from the 2005-06 Zimbabwe Demographic and Health Survey are consistently lower than estimates from the other demographic and health surveys because the bias due to HIV/AIDS increases during the course of the HIV epidemic, thus the extent of this bias is greater for the 2005-06 estimates.

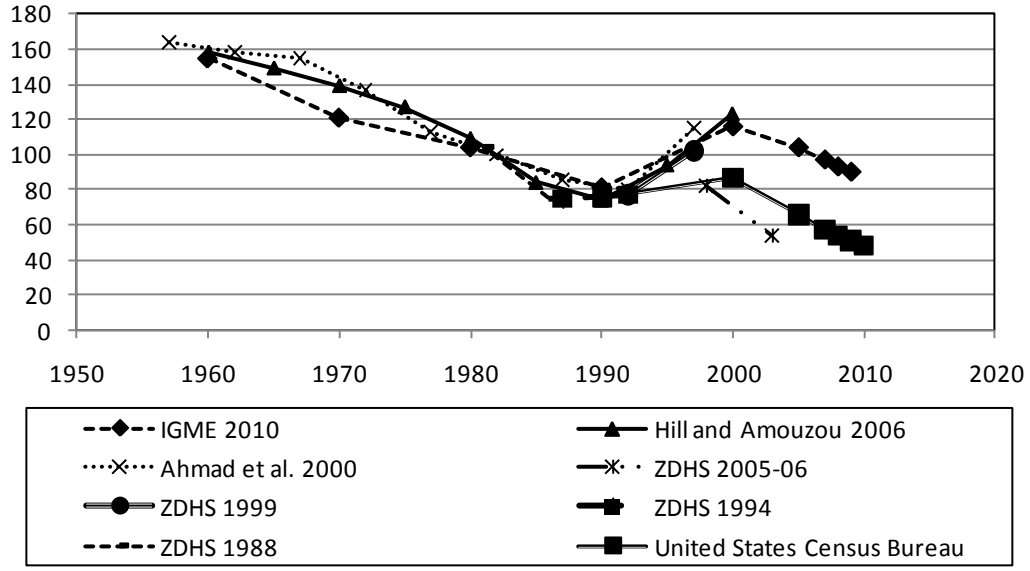
During the pre-epidemic period prior to 1990, the infant mortality rate in Zimbabwe declined from about 100 deaths per 1,000 live births in 1960 to around 50 deaths per 1,000 live births in 1990. It then increased during the first decade of the HIV/AIDS epidemic from 1990 to 2000, to about 70 deaths per 1,000 live births in 2000. The infant mortality rate then gradually declined for the period from 2000 to 2009, to about 44 deaths per 1,000 live births in 2009.

Figure 2.1 IMR trends in Zimbabwe by author, organisation or data source



The under-five mortality rate in Zimbabwe declined from about 160 deaths per 1,000 live births in 1955 to around 80 deaths per 1,000 live births in 1990. It then increased during the 10-year period from 1990 to 2000, to about 120 deaths per 1,000 live births in 2000. The under-five mortality rate then gradually declined to about 70 deaths per 1,000 live births in 2009. From the year 2000, there is wide variation in the estimates produced by the different researchers. The estimates by the IGME (2010) for this period are the most plausible because they are adjusted for the bias due to HIV.

Figure 2.2 U5MR trends in Zimbabwe by author, organisation or data source



There is a downward trend in child mortality in Zimbabwe during the pre-epidemic period prior to 1990, and an apparent reversal in these gains in child survival in the ensuing decade. This reversal in child health gains is associated with the advent of HIV and the adverse effects of the economic structural adjustment program (ESAP) adopted in 1991 that led to a reduction of government spending on provision of health and social services (ZHDR 2003). The decline in child mortality in Zimbabwe that started after the first decade of the HIV/AIDS epidemic is possibly a result of the decline in the HIV prevalence of women and the increase in the prevention of mother-to-child transmission (PMTCT) programs that occurred after 2002 (Halperin, Mugurungi, Hallet *et al.* 2011; UNAIDS 2005).

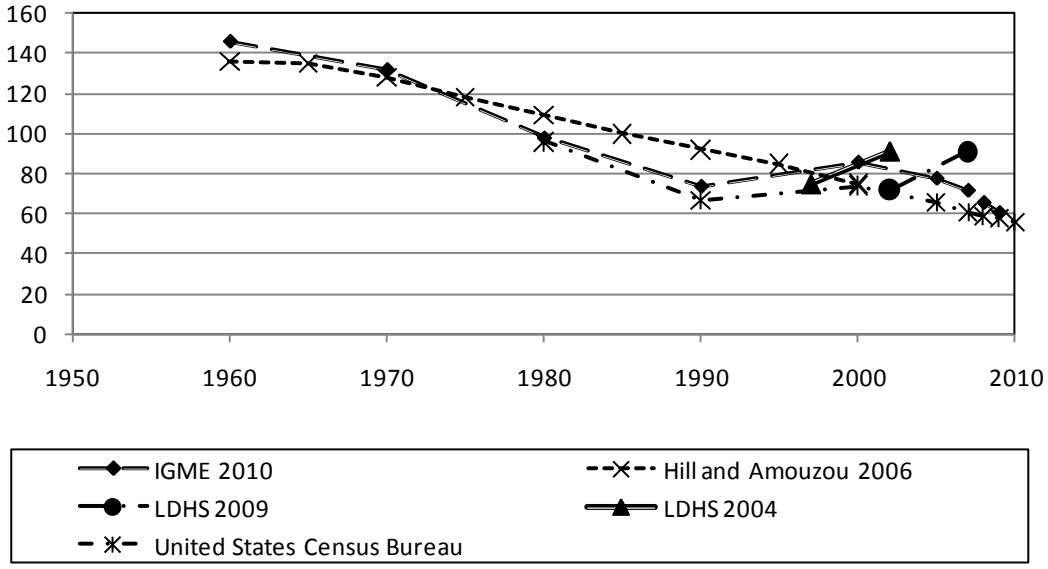
Figure 2.3 and Figure 2.4 show respectively, the trends in estimates of infant and under-five mortality rates for Lesotho produced by the sources reviewed in this research together with the trends inferred from two successive five-year periods preceding the 2009 and 2004 Lesotho Demographic and Health Surveys (LDHS), and trends produced by the United States Census Bureau (2011).

The first case of HIV in Lesotho was reported in 1986 (USAID 2010a). Thus, the decade when HIV/AIDS first exerted a significant impact on childhood mortality in the country is expected to have started around the early 1990s.

The 2009 and 2004 Lesotho Demographic and Health Surveys produce inconsistent estimates of both the infant and under-five mortality rates for overlapping time periods. Estimates derived from the 2009 DHS data are lower than the 2004 estimates in the overlapping period because the bias due to HIV/AIDS increases during the course of the HIV epidemic, thus the extent of this bias is greater for the 2009 estimates. The different sampling frames used to select the samples for the two surveys could be another reason for the inconsistency in the two series of estimates for overlapping periods.

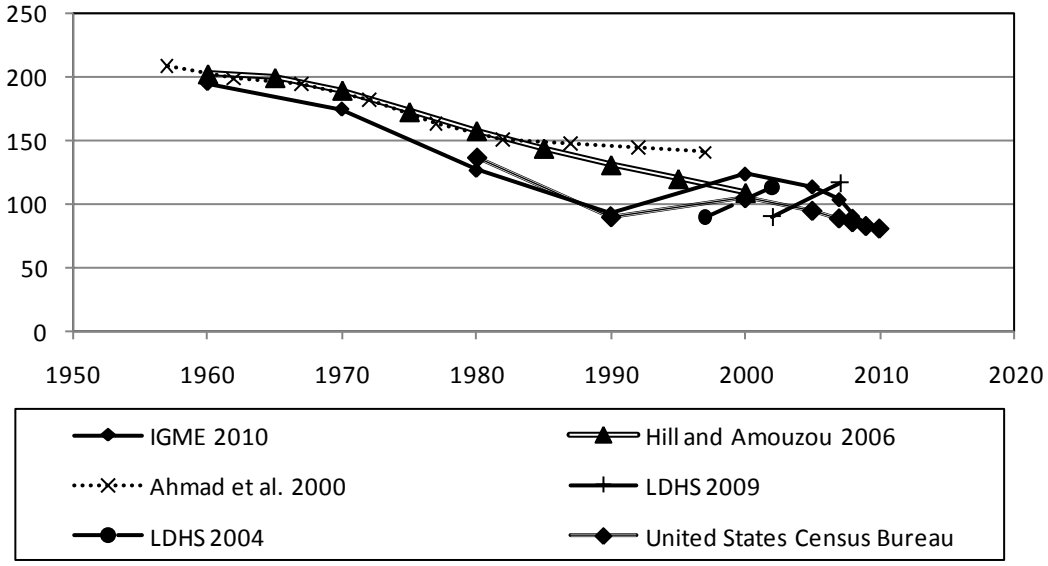
The infant mortality rate in Lesotho gradually declined during the pre-epidemic period from about 140 deaths per 1,000 live births in 1960 to around 80 deaths per 1,000 live births in the early to the mid-1990s. It then increased slightly to about 100 deaths per 1,000 live births in 2007.

Figure 2.3 IMR trends in Lesotho by author, organisation or data source



The under-five mortality rate in Lesotho gradually declined from about 200 deaths per 1,000 live births in 1955 to around 100 deaths per 1,000 live births in the early to the mid-1990s. It then increased slightly to about 120 deaths per 1,000 live births in 2007.

Figure 2.4 U5MR trends in Lesotho by author, organisation or data source



There is a downward trend in child mortality in Lesotho during the pre-epidemic period prior to the early 1990s, and an apparent reversal in these gains in child survival in the period up to 2007. This reversal in child health gains is attributed to the high HIV prevalence of 23.6 per cent, the third highest in world (MoHSW and ICF Macro 2010;

CBL 2009). From the year 1990, the estimates by the IGME (2010) are the most plausible because they are adjusted for the bias due to HIV/AIDS.

3 DATA AND METHODS

3.1 Introduction

This chapter presents the sources of the data used in the study, and an evaluation of their quality. The methods used to adjust the full birth history data for the bias due to HIV/AIDS and to estimate childhood mortality are presented. The chapter also presents the method used to derive the overall bias in the own-child method due to HIV/AIDS and the contribution of the four components to the overall bias. Section 3.2 gives the data sources. The assessment of the quality of these data is presented in Section 3.3. Section 3.4 describes how the full birth history data are first adjusted for the bias due to HIV/AIDS before the own-child method is applied to derive the estimates of childhood mortality. Section 3.5 outlines how the estimates of infant and under-five mortality rates are derived by applying the fundamental equation (1) of the own-child method and the approach proposed by Preston and Palloni (1977) to the data that are both unadjusted and adjusted for the bias due to HIV/AIDS. The method used to derive the overall bias in the own-child method due to HIV/AIDS and the contribution of four components to the overall bias is presented in Section 3.6.

3.2 Data sources

This study uses the 2009 Lesotho Demographic and Health Survey (LDHS) and the 2005-6 Zimbabwe Demographic and Health Survey (ZDHS) data to derive infant and under-five mortality rates using the own-child method and estimate the extent of the bias in the own-child method due to HIV/AIDS in Lesotho and Zimbabwe. Data collection for the 2009 LDHS took place from 16 October 2009 to 26 January 2010 and the 2005-6 ZDHS was conducted from August 2005 to February 2006. In both surveys, the questionnaire for women aged 15-49 collected, among other data, the birth history of each eligible woman and data regarding child mortality. In addition, the study uses the 1988 Zimbabwe Demographic and Health Survey, conducted during the early stages of the HIV/AIDS epidemic in Zimbabwe. This is done in order to assess the internal consistency and the temporal variation of the estimates of the bias in the own-child method due to HIV/AIDS.

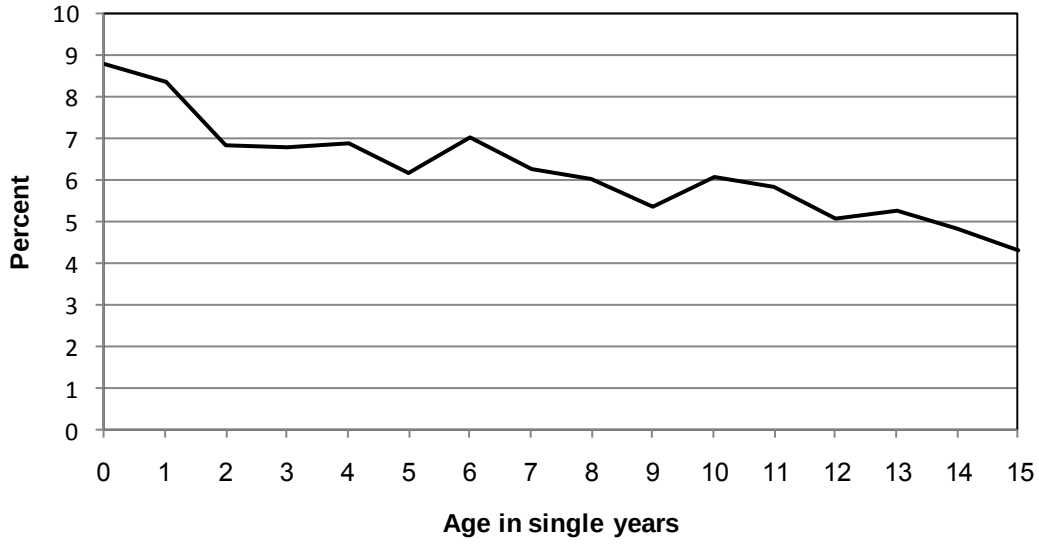
3.3 Data quality

The quality of the data regarding age, number of children ever born, reported births and reported number of children dead is assessed before being used to derive estimates of infant and under-five mortality rates.

3.3.1 Distribution of the ages of children and women, Lesotho DHS 2009

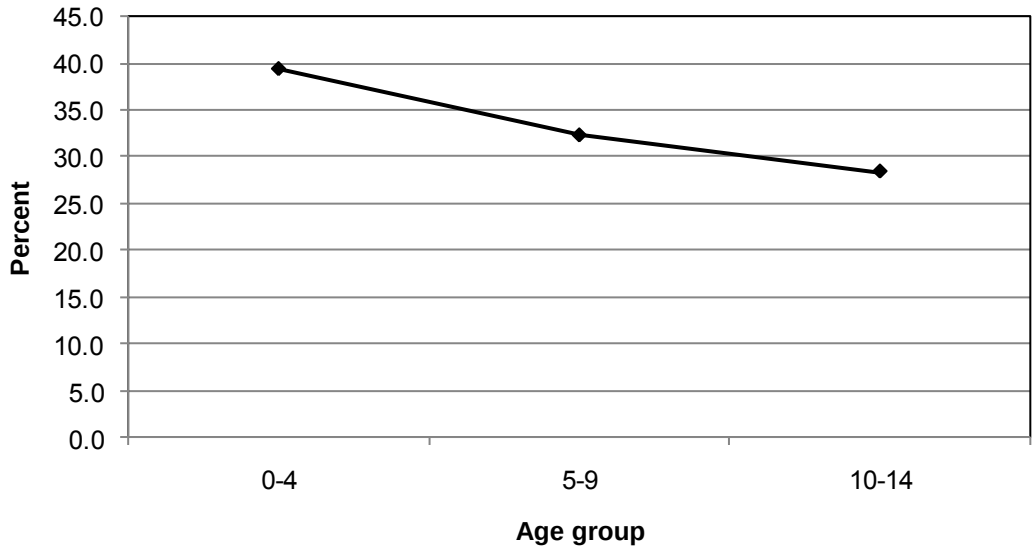
The own-child method is sensitive to errors in the reporting of the ages of children and women. Age misreporting includes digit preference (or age heaping), and under and overstatement of ages. The application of the own-child method used in this study relies on the age distribution of the surviving children aged below 15 years of each woman in a household. We assessed the quality of data with respect to age graphically by examining the proportionate age distribution of children aged below 15 years. The proportionate distribution should decrease with increasing age, unless there are defects in the age data and the data are affected by migration. The proportionate distribution of the children by age in single years exhibits fluctuations that are indicative of age heaping or digit preference (Figure 3.1). In particular, the reporting of the ages of children below the age of ten indicates the preference of even digits, and after the age of ten, a preference for ages ending with odd digits. The misreporting of age, apparent in the fluctuations in the age data by single years for children aged below 15 years, distorts the proportionate age distribution of surviving children, i.e. the $c_s(a)$ values, and could therefore undermine the accuracy of the estimates derived from the method.

Figure 3.1 Percentage distribution of the child population by age in single years, Lesotho DHS 2009



The evaluation reveals that the proportionate distribution of the surviving children by age groups is smoother than the proportionate distribution by single years because five-year age groups are only affected by errors due to the transfers from one age group to another (Figure 3.2). The proportionate distribution of surviving children by age groups also depicts the expected gradual decline with increasing age and there appears to be no evidence of an undercount of the 0-4 year age group in the 2009 LDHS.

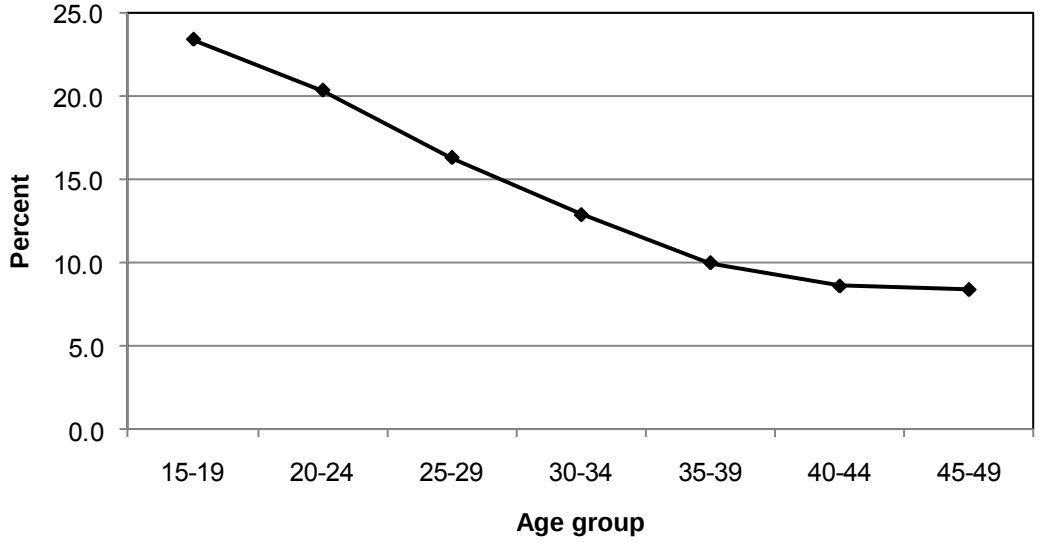
Figure 3.2 Percentage distribution of the child population by grouped age, Lesotho DHS 2009



3.3.2 Age distribution of Lesotho women aged 15-49

To minimize the effects of age misreporting, the study aggregates data for women using five-year age groups. The proportionate age distribution of the women aged 15-49 presented in Figure 3.3 also depicts the expected pattern of the percentage age distribution that decreases with increasing age.

Figure 3.3 Percentage age distribution of women aged 15-49, Lesotho DHS 2009

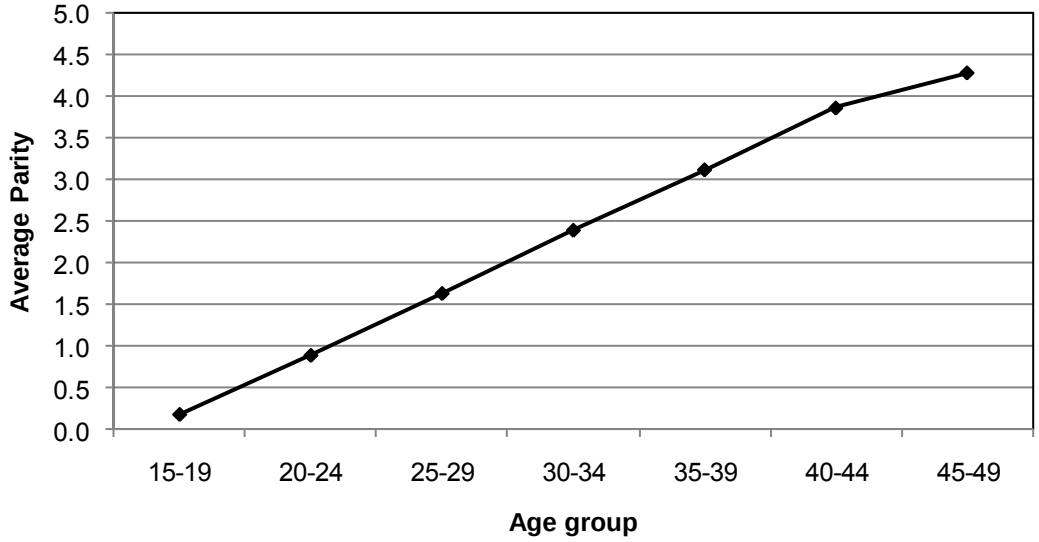


3.3.3 Parities of Lesotho women aged 15-49

The data on children reported ever born collected as part of the full birth history is affected by errors due to omission of children from the retrospective reports of women (United Nations 1983). Children who do not reside in the same household as their mothers are more likely to be omitted (United Nations 1983). The omission of surviving children relative to children that have died induces an upward bias in the estimates of child mortality. Child mortality rates are also overestimated if stillbirths are included among the children reported ever born (United Nations 1983; Rutstein and Guillermo 2003). In contrast, the erroneous inclusion of adopted children among children ever born causes child mortality rates to be underestimated.

The average parity is calculated by dividing the number of children ever born to women in an age group by the total number of women in that age group. The study evaluated the quality of data on the reported number of children ever born by examining the variation in the calculated average parities by age group of the mother. Barring an increase in fertility in the past, the average parities are expected to increase with age because older women have more children than younger women. The average parities of Lesotho women aged 15-49 in the 2009 LDHS, shown in Figure 3.4 conform to the expected pattern of parities that increase with increasing age of the mother. There is no evidence of omission of children from the reports of children ever born.

Figure 3.4 Average parities of women aged 15-49, Lesotho DHS 2009



3.3.4 Sex ratios of children ever born by Lesotho women aged 15-49

We also assessed the quality of data on the reported number of children ever born for differential omission with respect to the sex of the child or misreporting of the sex of the children reported ever born by examining the sex ratios of children ever born by age group of the mother (Table 3.1). The sex ratio is defined as the number of males per 100 females. The sex ratio at birth of the population as a whole is not expected to vary much over time and for populations in Eastern and Southern Africa its value should be close to 100 (Garenne 2004). Given that the sex ratio at birth changes very little over time and that women are expected to report all of their children they have borne alive, whether these children are alive or not at the time of the survey, the sex ratios of children ever born should likewise be generally stable or exhibit little and unsystematic variation across the age of the mothers and they should be close to 100. The sex ratios of children ever born presented in Table 3.1 vary considerably across the ages of the mothers although there is no systematic pattern in the observed variation. The variation of the sex ratios of children ever born by the ages of the mothers is probably due to the small numbers of children ever born rather than irregularities in the data.

Table 3.1 Sex ratios of children ever born to women aged 15-49, Lesotho DHS 2009

Age group	Children ever born		Sex Ratio
	Male	Female	
15-19	146	164	88.9
20-24	722	651	110.9
25-29	1036	991	104.5
30-34	1205	1144	105.4
35-39	1247	1134	109.9
40-44	1251	1284	97.4
45-49	1483	1263	117.4
Overall	7090	6632	106.9

3.3.5 Reported number of births by calendar year before the survey

To avoid asking additional questions (regarding immunisation, pregnancy, and antenatal care) that are asked of all births that occurred since the start of the fifth calendar year before the survey, as well as anthropometric measurement of children below the age of five years, interviewers may be motivated to report the births of the fifth as births in the sixth calendar year before the survey (Marckwardt and Rutstein 1996; Zhao 2011). The displacement of births from the fifth to the sixth calendar year before the survey distorts the estimated trends in childhood mortality (Zhao 2011). The study checked for the displacement of births by assessing the birth-year ratios for the fifth and the sixth calendar years prior to the Lesotho 2009 DHS. The birth-year ratios shown in Table 3.2 are calculated using the formula: $BYR = \frac{200 * B_x}{[B_{x-1} + B_{x+1}]}$, where B_x is the number of births in calendar year *x*.

Table 3.2 Birth-year ratios of all children, surviving children and dead children, Lesotho DHS 2009

Year	All children	Surviving children	Dead children
1995	147.4	147.4	146.7
1996	105.7	106.1	102.1
1997	93.3	90.9	122.6
1998	102.9	106.9	67.6
1999	106.0	106.1	104.7
2000	97.1	90.8	168.5
2001	96.1	102.0	49.7
2002	96.6	95.9	103.6
2003	112.3	111.0	126.3
2004	90.5	92.8	72.2
2005	104.9	102.7	124.0
2006	99.5	99.6	98.5
2007	91.9	90.6	103.3
2008	113.6	113.6	113.4

The birth-year ratio for all children is less than 100 for the calendar year 2004 while that for the year 2003 is greater than 100. In particular, the value of $BYR = \frac{200 * B_5}{[B_4 + B_6]}$ for the calendar year centred on 2004 of 90.5 is in the range $90 \leq BYR < 95$. This is indicative of a slight birth displacement problem from the fifth calendar year prior to the survey, 2004 to the sixth, 2003 (Zhao 2011).

The differential displacement of the births from 2004 to 2003 by the survival status of the births at the time of the survey was checked using the birth-year ratios of the children dead and children surviving that are centred on the calendar year 2004. The birth-year ratio for the children dead is smaller than that for the children surviving, thus there is more displacement of births from 2004 to 2003 among dead children than among the children surviving (Zhao 2011).

Since birth displacement from the fifth year prior to the survey to the sixth year is a more serious problem among dead children than the surviving children, the estimates of the infant and the under-five mortality for the period 0-4 years prior to the survey are underestimated while the infant and the under-five mortality for the period 5-9 years prior to the survey are overestimated.

To minimize the effects of birth displacement in the 2009 LDHS, the study derived the estimates of the infant and the under-five mortality for the periods 1-5, 6-10

and 11-15 years prior to the survey instead of the periods 0-4, 5-9 and 10-14. These estimates of the infant and the under-five mortality are presented in Table 3.3 below.

Table 3.3 Infant and under-five mortality by five-year periods before the Lesotho DHS 2009

	Period							
	0 - 4	1-5	5-9	6 – 10	10-14	11-15	15-19	16 - 20
Infant mortality ($_1q_0$)	91.5	91.9	72.2	67.2	56.7	58.0	71.6	63.8
Under-five mortality ($_5q_0$)	116.8	119.2	90.4	83.7	70.7	72.5	83.3	74.5

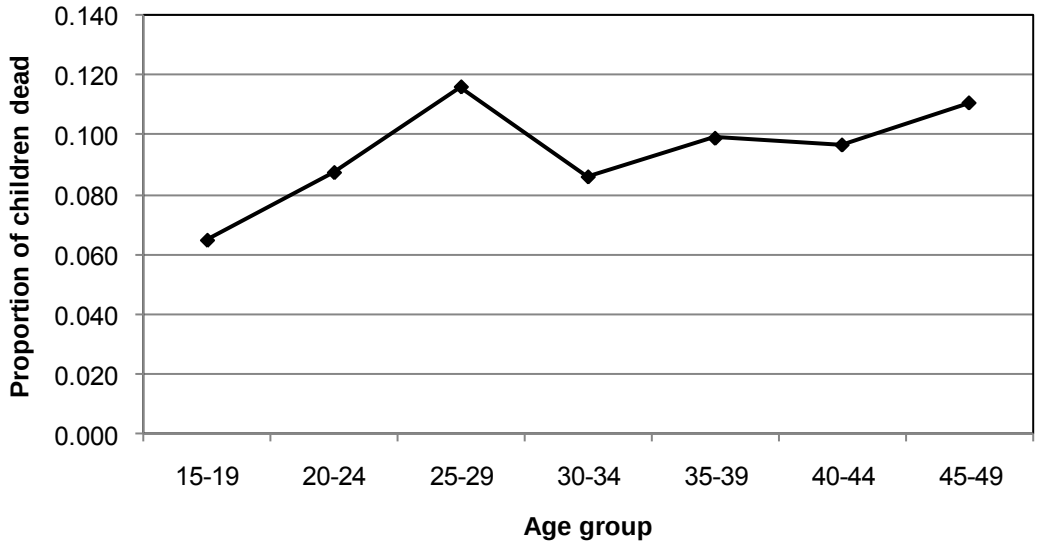
A comparison of the infant and the under-five mortality for the periods 1-5, 6-10, . . ., 16-20 years prior to the survey with those for the periods 0-4, 5-9, . . ., 15-19 confirms that the infant and the under-five mortality are underestimated for the period 0-4 years prior to the survey and overestimated for the period 5-9 years prior to the survey. The infant and the under-five mortality are also underestimated for the period 10-14 years prior to the survey and overestimated for the period 15-19 years prior to the survey.

3.3.6 Proportions of children reported dead by Lesotho women aged 15-49

Women often omit children who died during the early stages of life and older women are more likely to omit children who died at the onset of their childbearing (United Nations 1983). In some cultures, deaths of children may be underreported because women are reluctant to discuss details of their children who have died (Trussell and Menken 1984; Hill and Montana 2011). Child mortality is underestimated when children that have died are omitted relative to the children still surviving (Hill 1991).

The study checked the quality of data on the reported number of children dead for possible omission of dead children by examining the proportions of dead children by age of mother (Figure 3.5). Barring the proportion of children reported dead by women aged 15-19 that is expected to be abnormally high, we expect the other proportions to increase with increasing age of the mother because on average, the duration of exposure to the risk of dying of the children of older women is longer compared to the children of younger women.

Figure 3.5 Proportions of children reported dead by women aged 15-49, Lesotho DHS 2009



The proportion of children reported dead by women aged 15-19 is expected to be higher but it is lower than the proportions for women in subsequent age groups, probably because for this age group the number of children dead is small. If the value for this age group is disregarded, we find that there is a gradual increase in the proportions of children reported dead from the age group 20-24 up to the age group 45-49, although there is a trough at the age group 30-34.

On the whole, the assessment of the 2009 LDHS did not reveal any serious defects in the data that would invalidate their use to estimate childhood mortality rates. A similar evaluation of the 2005-6 ZDHS (Appendix A) did not find any serious flaws in the data. In addition the evaluation did not find evidence of birth displacement.

3.4 Adjusting the 2009 Lesotho DHS full birth history data for the bias due to HIV

Before the own-child method is applied to derive the estimates of the infant and the under-five mortality rates, the full birth history data of the 2009 Lesotho DHS is first adjusted for the bias due to HIV, as outlined below. In the process, we also derive the target levels of childhood mortality in Lesotho.

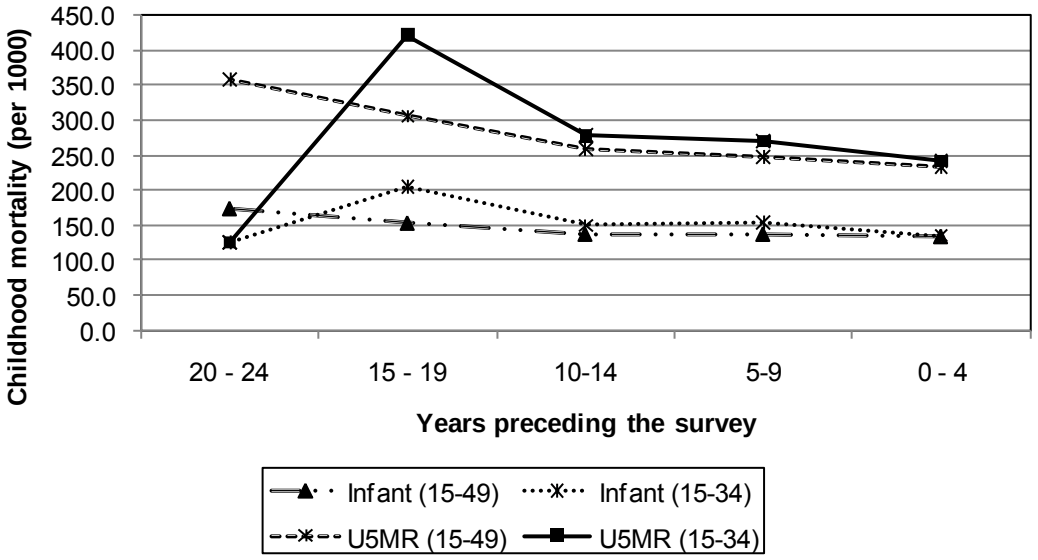
We calculated, first, the direct estimates of infant and under-five mortality rates for the three, five-year periods, 1-5, 6-10 and 11-15 years preceding the date of the survey using the full birth history data of reporting women between the ages 15 and 49 years. As mentioned earlier, the direct estimates are calculated for the periods, 1-5, 6-10 and 11-15 years prior to the survey instead of the periods 0-4, 5-9 and 10-14, in order to

minimise the problem of the displacement of births in the 2009 LDHS that was detected in section 3.3.5.

The infant and the under-five mortality rates that are calculated for each of these five-year periods are underestimated because they are based on birth history data of women who survived to be interviewed, and thus the deaths of children of women who died, mostly of AIDS, are excluded. The target estimates of the infant and under-five mortality rate, $q^c(1)$, and $q^c(5)$, are then calculated by adjusting these estimates for the bias due to HIV/AIDS using the correction factors by Hill and Walker (personal communication with K. Hill. 2011). A description of the workbook produced by Hill and Walker, and how it was modified in order to obtain the adjusted estimates of the infant mortality rate is provided in Appendix B.

It should be noted though, that this study derives the estimates of $q(1)$ and $q(5)$ based on the reports of women in the age range 15 to 34, while the correction factors by Hill and Walker are based on the annual births of women in the reproductive age range 15-49. To apply the correction factors by Hill and Walker, the study assumes that the estimates of $q(1)$ and $q(5)$ derived on the basis of reports of women between the ages 15 and 34 do not differ significantly from the estimates that are derived based on the reports of women in the reproductive age range 15-49 years. The reasonableness of this assumption was tested using the $q(1)$ and $q(5)$ values calculated for the two age ranges of women using the full birth history data of the 1992 Malawi DHS, a survey conducted before the HIV/AIDS epidemic was a significant factor. As can be seen from Figure 3.6, the assumption appears to be quite reasonable for the 15 years immediately prior to the survey. The fluctuations in the estimates of infant and under-five mortality rates derived from the reports of women in the age range 15-34 years for the periods further back in time from the survey is probably random fluctuations due to the few numbers of births and deaths. Thus, the age range 15-34 is a good approximation to the age range 15-49 for the period 0-14 years before the survey.

Figure 3.6 Childhood mortality of children born to women aged 15-34 and 15-49, Malawi DHS 1992



Having derived the corrected full birth history estimates of the infant and under-five mortality rate, the next step is to utilize these data to estimate the variation of the bias in the unadjusted estimates due to HIV/AIDS by the age of the child, *a*, for *a*=1, 2, 3, …, 15. Considering the 2009 LDHS to have been conducted at a time t_s, we used STATA to extract the number of births *a* years before the time $t_s - 1$ because the estimates of the infant and under-five mortality rate are for the periods 1-5, 6-10 and 11-15 instead of the periods 0-4, 5-9 and 10-14 years preceding the survey. For ease of notation, we denote the time $t_s - 1$ as t_t. Thus, these births, denoted $B(t_t - a)$, occur during the period $t_t - a - 0.5$ and $t_t - a + 0.5$. We also extracted the number of those births that survive and are aged *a* nearest birthday, i.e. aged between $a - 0.5$ and $a + 0.5$ at the time t_t, as reported by women in the age range 15-34 years last birthday at the time of the survey. We use $S(a)$ to denote the number of surviving children aged *a* nearest birthday. The number of children ever born to reporting women, denoted as *B*, the number of those children ever born that survive to the time t_t, *S*, the proportion of surviving children who are aged *a* nearest birthday at the time t_t, $c_s(a)$, and the cohort probability of surviving to age *a*, $p(a)$, are estimated from the values of $B(t_t - a)$ and $S(a)$ using the following equations:

$$B = \sum_{a=1}^{15} B(t_t - a),\ S = \sum_{a=1}^{15} S(a),\ c_s(a) = \frac{S(a)}{S},\ \text{and}\ p(a) = \frac{S(a)}{B(t_t - a)},\ \text{respectively.}$$

For each of the three five-year periods, 0-4, 5-9 and 10-14 years preceding the time t_t, the estimate of the target cohort probability of surviving to age 5, $p^c(5)$, obtained by subtracting each $q^c(5)$ value for that period from 1, corresponds, approximately, to a period rate at a point in the middle of the five-year period. Thus, for example, for the first five-year period before time t_t, $p^c(5) = 1 - q^c(5)$ corresponds to $p^*(5)$, the proportion of the births that occurred five years before the time t_t who are reported by women alive at the time of the survey to have survived the first five years of life. Assuming that the value of $p^c(5)$ is accurate, the bias in that cohort, i.e. in the value of $p(5)$, due to HIV, $b(5)$, is estimated by: $b(5) = \frac{p^*(5) - p^c(5)}{p^c(5)}$.

Similarly, $p^c(1) = 1 - q^c(1)$ corresponds to $p^*(1)$, the proportion of the births that occurred three years before the time t_t who are reported by women alive at the time of the survey to have survived the first year of life. Assuming that the value of $p^c(1)$ is accurate, the bias in that cohort, i.e. in the value of $p(3)$, due to HIV, $b(3)$, is estimated by: $b(3) = \frac{p^*(1) - p^c(1)}{p^c(1)}$, on the assumption that most of the bias in $p(3)$ is captured in the first year of life.

Estimates of $b(10)$ and $b(8)$ are calculated by repeating this procedure for the second five-year period preceding the time t_t. Likewise, we estimate $b(15)$ and $b(13)$ by repeating the procedure for the third five-year period preceding the time t_t.

The study derived an alternative set of the estimates of the bias due to HIV/AIDS as follows. First, the proportion of the births that survive to age *a*, $p(a)$, was estimated by fitting to the ages of children the curve of life table survivors, $l(a)$ proposed by Blacker and Brass (2005):

$$l(a) = (1 + \alpha a)^{-\beta},$$

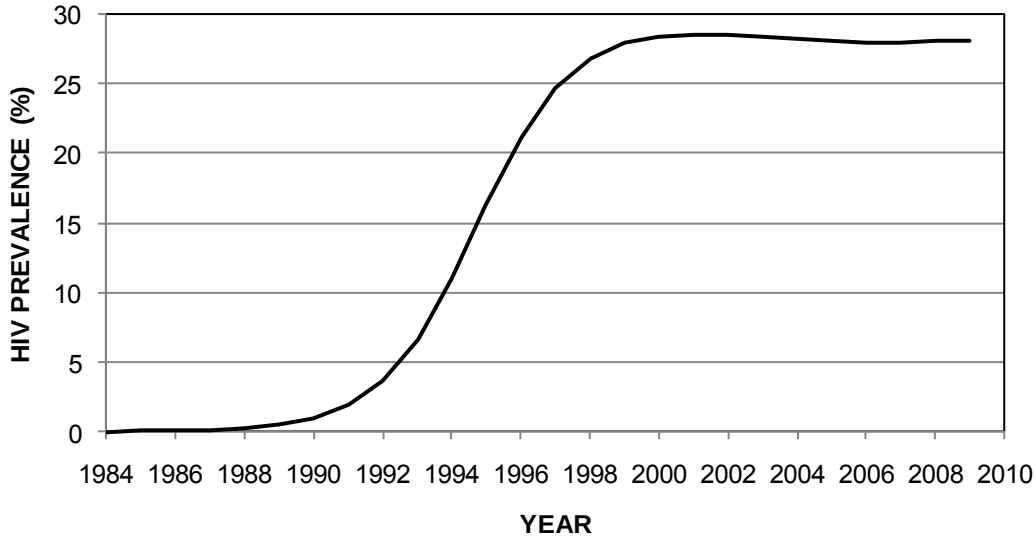
where, *a* is the age in years, α is a constant representing the pattern of the death rates and β is a constant representing the level of the death rates. For a life table with a radix of one, $l(a) = p(a)$. We derived the estimates of $p(a)$ for ages up to ten years which we denote $p_{BB}(a)$, by fitting the curve using the values of $p^c(1)$ and $p^c(5)$ for the first

five-year period before time t_t, i.e. the period 1-5 years preceding the 2009 LDHS to solve for α and β.

The estimates of the bias, $b(a)$ for a=1, 2, 3, …, 10, were then calculated using the cohort survival probabilities, $p(a) = \frac{S(a)}{B(t_t - a)}$, and the survival probabilities that are derived by fitting the curve suggested by Blacker and Brass (2005), the $p_{BB}(a)$ values. Assuming that the curve fitted using the model by Blacker and Brass (2005) provides accurate estimates of the values of $p(a)$, these other estimates of the bias are calculated using the equation: $b(a) = \frac{p(a) - p_{BB}(a)}{p_{BB}(a)}$.

The magnitude of the bias due to HIV is expected to be low for recent births because women who can conceive and give birth are likely to survive for at least a short period of time and be alive to report the births and deaths of their children at the time of the survey. The bias is expected to increase with the age of the child because of the increased likelihood of maternal deaths. The bias also increases when the HIV prevalence among pregnant women increases. Figure 3.7 shows the SPETRUM projection of the HIV prevalence among women in the age range 15-49 in Lesotho.

Figure 3.7 HIV prevalence among women aged 15-49, Lesotho



Source: The Joint United Nations Programme on HIV/AIDS (UNAIDS)

At the time t_t, i.e. 2008, the bias due to HIV is expected to reach a peak at the child ages around 7, 8 and 9 years, corresponding to births that occurred during the years 2001, 2000 and 1999 respectively when the HIV prevalence reached a plateau in

Lesotho. At this time point, t_t, i.e. 2008, the bias at the older child ages of 12 to 15 years, is expected to be low because their births occurred between 1993 and 1996 when the prevalence was relatively low and a few children would have been infected at or around birth. The functional form of this relationship between the ages of the children and the bias is thus assumed to be quadratic.

Thus, at age one we assume that the bias due to HIV is close to zero because women who can conceive and give birth are likely to be alive one year after giving birth. We then fit a quadratic curve to the estimated values of $b(1)$, $b(3)$, $b(5)$, $b(8)$, $b(10)$, $b(13)$ and $b(15)$ together with all the additional values of $b(a)$ from the model by Blacker and Brass (2005). The quadratic curve of the bias due to HIV/AIDS that was fitted to the ages of children is shown in Appendix C. The curve is used to estimate the bias due to HIV for each age *a*=1, 2, 3, . . ., 15.

The research uses the fitted values of $b(a)$ to estimate the corrected cohort probability of surviving to age *a*, $p^c(a)$, adjusted for the bias due to HIV as:

$p^c(a) = \frac{p(a)}{b(a)+1}$ for *a*=1, 2, 3, . . ., 15.

For the second and third five-year periods preceding the time t_t, the calculation of the bias in $p(8)$ and $p(13)$ requires an estimate of $p^*(1)$, the proportion of the births that occurred eight and thirteen years before the time t_t, respectively, who are reported by women alive at the time of the survey to have survived the first year of life. The use of $p^*(1)$ may fail to provide a true indication of the bias in $p(8)$ and $p(13)$, if most of the bias in the values of $p(8)$ and $p(13)$ is not captured in the mortality at the ages below one. Similarly, for these two five-year periods preceding the time t_t, the calculation of the bias in $p(10)$ and $p(15)$ requires an estimate of $p^*(5)$, the proportion of the births that occurred ten and fifteen years before the time t_t, respectively, who are reported by women alive at the time of the survey to have survived the first five years of life. Again, the use of $p^*(5)$ may fail to provide an accurate measure of the bias in $p(10)$ and $p(15)$, if most of the bias in the values of $p(10)$ and $p(15)$ is not captured in the mortality at the ages below five years.

We verified that the use of $p^*(1)$ and $p^*(5)$ gives reliable estimates of the bias by comparing the estimates of $p^c(a)$ derived using the curve of the HIV selection bias for

the ages *a*=1, 2, 3, …, 10 against the corresponding estimates derived by fitting the curve suggested by Blacker and Brass (2005), the $p_{BB}(a)$ values (Table 3.4).

Table 3.4 Percentage difference of the probabilities of surviving to age *a*, $p_{BB}(a)$ and $p^c(a)$

Child ages (a)	$p_{BB}(a)$	$p^c(a)$	Difference (%)
1	0.900	0.915	1.7%
2	0.884	0.877	-0.8%
3	0.875	0.856	-2.2%
4	0.869	0.862	-0.7%
5	0.864	0.869	0.6%
6	0.860	0.862	0.3%
7	0.856	0.877	2.4%
8	0.853	0.861	0.9%
9	0.851	0.815	-4.2%
10	0.849	0.882	3.9%

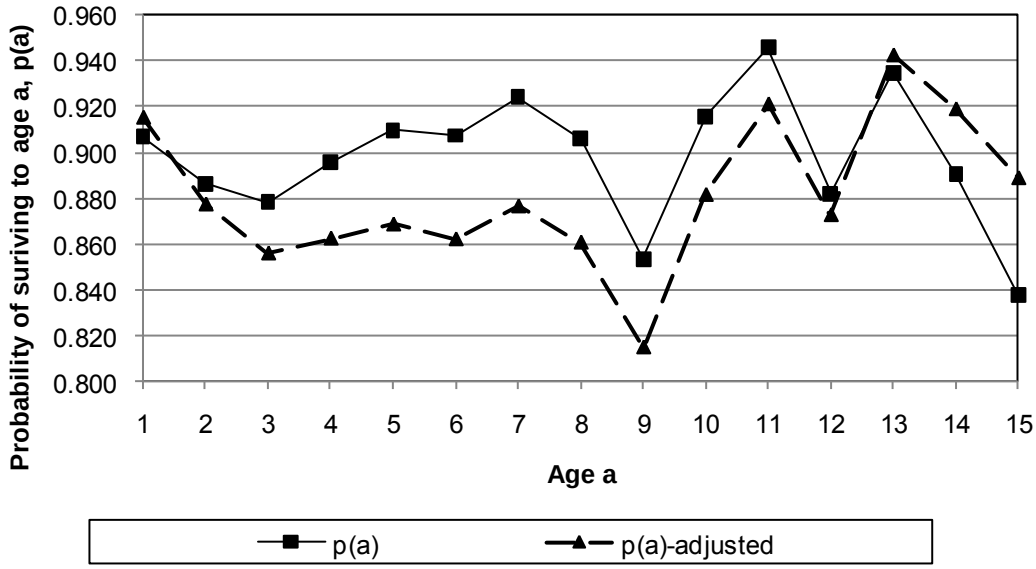
The estimates of the $p^c(a)$ values derived using the curve of the HIV selection bias differ slightly from those derived by fitting the curve suggested by Blacker and Brass (2005). The percentage difference of the estimates is less than 5 per cent for all the ages *a*=1, 2, 3, …, 10.

Assuming that the curve fitted using the model by Blacker and Brass (2005) provides accurate estimates of the values of $p(a)$, the use of $p^*(1)$ provides a realistic indication of the bias in $p(3)$, $p(8)$ and $p(13)$. Similarly, the use of $p^*(5)$, provides a realistic indication of the bias in $p(5)$, $p(10)$ and $p(15)$.

Thus, it appears to be reasonable to use this approach to adjust the values of the cohort probability of surviving to age *a*, $p(a)$, for the bias due to HIV using the estimates of the bias derived by fitting the quadratic curve.

The study also checked the reasonableness of the cohort survival probabilities that are both unadjusted and adjusted for the bias due to HIV using the bias estimated by fitting the quadratic curve (Figure 3.8).

Figure 3.8 Probabilities of surviving to age a, $p(a)$, 2009 LDHS



Although in the absence of HIV/AIDS the cohort survival probabilities are expected to decrease with the increasing age of the child, HIV/AIDS causes the $p(a)$ values to increase with the age of the child because of the increased likelihood of maternal deaths. The pattern by age of the estimates is volatile at the older ages, probably because the $p(a)$ values for these ages are calculated based on small numbers of births and surviving children. The births and deaths of dead children were probably underreported because women are reluctant to discuss details of their children who have died. The fluctuations in the age pattern of the survey estimates exhibited at the older ages could also be due to anomalies in the survey data with regard to the retrospective reporting of the dates of birth of children born further back in time from the survey date.

The estimates that are corrected for the bias introduced by HIV using the bias derived by fitting the quadratic curve provide a significant downward adjustment to the uncorrected estimates.

The full birth history data of the 2005-6 ZDHS was adjusted for the selection bias due to HIV/AIDS in a similar manner.

3.5 Estimating infant and under-five mortality rates

The research uses the 2009 LDHS and 2005-6 ZDHS to estimate infant and under-five mortality rates by applying the fundamental equation of the own-child method and the approach proposed by Preston and Palloni (1977) to the full birth history data that are unadjusted for the bias due to HIV. We also derive estimates of childhood mortality

that are adjusted for the bias due to HIV by applying both versions of the own-child method to the full birth history data that are adjusted for the bias due to HIV.

3.5.1 Linking surviving children enumerated in the 2006 Lesotho census to their biological mothers using the software, MATCHTAB

Both applications of the own-child method require that we start by matching women at ages between 15 and 64 in each household to their biological children aged below 15 years using the matching software MATCHTAB. The study uses MATCHTAB to link the surviving children enumerated in the 2006 Lesotho census to their biological mothers. We then determine how well MATCHTAB links the surviving children to their biological mothers by applying the fundamental equation of the own-child method to the MATCHTAB output data, as described in Appendix D2. The results presented in Appendix D2 show that when we apply the fundamental equation of the own-child method to the 2006 Lesotho census data after linking women to their biological children using MATCHTAB, we get estimates of infant and under-five mortality rates that are quite close to those derived from the 2009 LDHS data without using MATCHTAB. Given the similarity of these estimates, MATCHTAB provides a successful link of women to their biological children enumerated in the 2006 Lesotho census. For the same reason, the study also takes advantage of the direct mother-child link provided by the full birth history of the demographic and health surveys instead of linking mothers to their biological children using MATCHTAB.

As noted earlier in section 2.5, the application of the own-child method can be compromised by the erroneous reporting of adopted or foster children as biological children. The information regarding the relationship to the head of household recorded on the household roster of the 2009 LDHS and the 2005-6 ZDHS indicates respectively that 0.6 and 1.7 per cent of households reported having adopted children who are under the age of 18 years. On the other hand, the proportion of households interviewed in the 2009 LDHS and the 2005-6 ZDHS that have double orphans, i.e. children under the age of 18 years with both parents being dead is 8.4 and 9 per cent respectively Given that the extent of orphan-hood reported by households is higher than the reported level of child fostering, it is possible that some orphaned children residing with foster parents are being reported as own children. Thus, the erroneous reporting of orphaned children as biological children could affect the application of the own-child method to the 2009 LDHS and 2005-6 ZDHS data. However, the effect of this is likely to be too small to invalidate the application of the own-child method.

3.5.2 Deriving child mortality rates by applying the fundamental equation of the own-child method to the data that are unadjusted and adjusted for the bias due to HIV

The data on the number of children born to women in the age range 15-34 years are tabulated for each of the fifteen years before the survey. We also tabulate the surviving children of women in the age range 15-34 by the child ages *a* nearest birthday at the time of the survey, for *a*=1, 2, 3, . . ., 15. We then identify the adjusted and unadjusted set of ${}_aq_0$ values that solve the fundamental equation of the own-child method as described respectively in Appendix D1 and D3.

For both Lesotho and Zimbabwe, we use the West family of the Princeton model life tables to identify the ${}_aq_0$ values. The choice of the West family is based on findings from the 2009 LDHS and 2005-6 ZDHS indicating that for both countries, the infant mortality is relatively higher than child mortality. Thus, we use the West family because it gives the most broad pattern and evidence from the demographic and health surveys suggest that the North family is inconsistent with the age pattern of childhood mortality in Lesotho and Zimbabwe. Although the age pattern of the West family of the Princeton model life tables is not suitable in high HIV/AIDS settings, the estimation of the bias in the own-child method due to HIV/AIDS require that the method be first applied as if there was no bias induced by the use of a standard non-AIDS model life table.

3.5.3 Deriving child mortality rates by applying the approach proposed by Preston and Palloni (1977) to the data that are unadjusted for the bias due to HIV

The data on children ever born and children surviving are classified by five-year age groups of mothers. The method by Preston and Palloni (1977) described in detail in Appendices D4 and D5 is then applied to derive estimates of childhood mortality that are, respectively, unadjusted and adjusted for the bias due to HIV/AIDS. The conversion of the child mortality indices derived from the data at each age group of mothers to common indices q_0, and ${}_5q_0$, and the calculation of the time location of these estimates is described in these appendices.

3.6 Estimating the bias in the own-child method due to HIV/AIDS

Having derived the unadjusted and the adjusted target estimates of the infant and under-five mortality rates, we estimate the extent of the bias in the own-child method due to HIV/AIDS and the contribution of two components to the overall bias.

The study estimates the overall bias due to HIV/AIDS in the own-child method as the difference between the $q^c(a) = 1 - p^c(a)$, derived from the full birth history data, and the $q_{ocm}(a) = 1 - p_{ocm}(a)$, estimated by applying the approach by Preston and Palloni to the data that are not corrected for the bias due to HIV/AIDS.

The direct estimates of the infant and under-five mortality rates are for the periods 0-4, 5-9, and 10-14 years preceding the survey. Thus, to get the difference between the two sets of estimates at comparable points in time, we first date the direct estimates of the infant and the under-five mortality rate using the mid-points of the five-year periods. We then interpolate the direct estimates using the dates of the indirect estimates from the method by Preston and Palloni (1977).

In deriving the overall bias due to HIV/AIDS, we note that the indirect estimates of the infant mortality rate are significantly higher than the direct estimates (Adetunji 1996). This is confirmed in section 4.2, where we show that the indirect estimates of the under-five mortality rate are also greater than the direct estimates. The difference between the direct and indirect estimates of the infant and under-five mortality rates is indicative of the methodological bias inherent in the own-child indirect method relative to the direct method. There is a bias in the indirect estimates derived using the own-child method that is caused by the violation of the method assumptions and data errors related to the reported ages, parities and children dead. The relative methodological bias exists in the absence of HIV/AIDS. Thus, the study is mindful of the contribution to the overall bias of this relative methodological bias. However, the direct estimates are themselves affected by data errors due to the misreporting of dates of births, ages at death and selective recall. Notwithstanding the possibility of the bias introduced by data errors, we assume that the direct estimates that are corrected for the bias due to HIV/AIDS provide the target level of childhood mortality in Lesotho and Zimbabwe.

In addition to the relative methodological bias, four HIV/AIDS related components contribute to the overall bias. These are: the bias due to the selection of women who survive to be interviewed (selection bias); the bias due to the use of a standard non-AIDS model life table to convert the estimates into common indices, q_0 and ${}_5q_0$ (conversion bias); the bias arising from the use of the regression coefficients by Preston and Palloni (1977); and the bias due to inaccurate time location estimates (coefficient and timing bias).

The study employs a life table estimated to apply during the year 2004, derived from a SPECTRUM projection of the Lesotho population, after incorporating the

effects of the HIV/AIDS epidemic, as the standard table in the Brass logit relational model, with $\beta = 1$, to determine the implied common measures of infant and under-five mortality that are adjusted for the conversion bias due to HIV/AIDS. Appendix E describes how the life tables incorporating HIV/AIDS for Lesotho and Zimbabwe were derived. The conversion bias is estimated as the difference between the common indices of infant and under-five mortality, derived using the data that are corrected for the selection bias due to HIV/AIDS and the life table from a SPECTRUM projection as the standard table, and the common indices derived using the data that are corrected for the selection bias and the Princeton model life tables as standard tables.

The difference between the overall bias and the conversion bias provides an indication of the coefficient and timing bias, and the relative methodological bias. Chitiyo (2011) shows that the coefficient and timing bias is small in comparison to the selection and conversion biases, particularly the selection bias. Thus, this study does not attempt to estimate the coefficient and timing bias because the difference between the overall bias and the conversion bias is mostly the relative methodological bias.

Finally, the selection bias is calculated as the difference between the $q^{c}_{ocm}(a)$ values, derived by applying the method by Preston and Palloni (1977) to data that are corrected for the selection bias, and the $q_{ocm}(a)$ values, estimated by applying the method by Preston and Palloni (1977) to the data that are not corrected for the selection bias due to HIV/AIDS.

4 RESULTS

4.1 Introduction

This chapter presents the results of applying the own-child method, and the estimates of the bias in the own-child method due to HIV/AIDS. Section 4.2 gives the results of applying the approach proposed by Preston and Palloni (1977) to the data that are unadjusted and adjusted for the bias due to HIV/AIDS. Section 4.3 presents the estimates of the overall bias in the own-child method due to HIV/AIDS as well as the estimated contribution of the selection bias and the conversion bias to the overall bias.

4.2 Childhood mortality estimates derived from the application of the approach proposed by Preston and Palloni (1977)

Table 4.1 provides the estimates of childhood mortality derived from the application of the approach proposed by Preston and Palloni (1977) to the data that are both, adjusted and unadjusted for the bias due to HIV/ADS. The tables of the data that are adjusted and unadjusted for the bias due to HIV/ADS are presented in Appendix F and the results of applying the fundamental equation of the own-child method to the unadjusted and adjusted data are presented in Appendix G.

Table 4.1 Childhood mortality, Preston and Palloni approach, Lesotho DHS 2009

Age groups of women (*i*)	Age of child (*a*)	${}_aq_0$	Time	${}_aq_0^c$	Time
15-19	1	40.1	2007.0	137.6	2007.5
20-24	2	92.0	2005.6	127.3	2005.7
25-29	3	109.7	2003.0	149.0	2003.3
30-34	5	82.1	2000.4	115.4	2000.3

The unadjusted estimate of the infant mortality, q_0, is low and unreliable because of the small numbers of children dead and children ever born to women in the youngest age group, 15-19. On the other hand, the adjusted estimate of the infant mortality is higher than the adjusted probability of dying at the older age of two. The adjusted estimate of the infant mortality is also very high when compared to the corresponding estimate of 89.6 deaths per 1,000 live births derived from the application of the fundamental equation of the own-child method (see Table G1, Appendix G for details). The estimates of the bias introduced by HIV/AIDS that we used to adjust the data for women in the age group 15-19 are probably erratic because of the small numbers of children ever born to women in this age group. The same pattern of results is found for

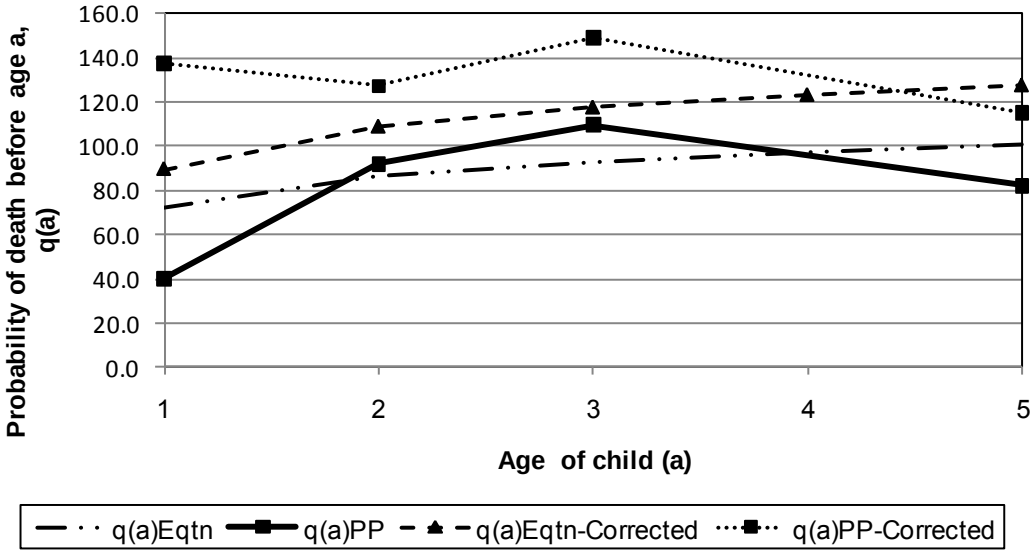
Zimbabwe (Table G3, Appendix G), with the exception that the estimate of the infant mortality is higher than the probabilities of dying at all the other older ages. Apart from the reasons cited above, this estimate is inconsistent with the estimates at the older ages because children of young mothers are subject to higher mortality.

The unadjusted and the adjusted estimates of the under-five mortality are both abnormally lower than the probabilities of dying at the younger ages of two and three. The inconsistency is probably due to anomalies in the data because the estimate of the under-five mortality is based on the reports of women aged 30-34. Their births occur on average five years before the survey and are likely to be shifted out of the fifth calendar year by interviewers keen to reduce their workload (Adetunji 1996). An inspection of the data recorded for women in the age group 30-34 reveals a deficit of births during the fifth year before the survey. The estimates of the under-five mortality are thus affected by the problem of birth displacement, alluded to in Section 3.3.5. Again, the evaluation of the data on the reported number of children dead (section 3.3.6) reveals that the proportion of children reported dead by women aged 30-34 is lower than the proportions of children reported dead by women in the age groups 20-24 and 25-29. This is indicative of the possible omission of dead children from the reports of the oldest women aged 30-34, especially children who died at the onset of their childbearing. Another reason could be that most of the births of women aged 30-34 occurred further back in time from the survey, at a time when the HIV prevalence was relatively low. Thus, the children born to women in this age group are subject to lower mortality because very few would have been infected at or around birth.

Both the unadjusted and the adjusted estimates of the under-five mortality are relatively lower than the corresponding estimates from the application of the fundamental equation of the own-child method. The estimates of the under-five mortality from the approach proposed by Preston and Palloni (1977) are based on the reports of women in the age group 30-34, while the estimates from the basic equation are derived from the reports of women in the broader age range 15-34. The estimates of the under-five mortality derived from the method by Preston and Palloni (1977) are abnormally lower, probably because of the anomalies in the data caused by the lower numbers of children surviving and children ever born to women in the age group 30-34 compared to those for women in the broader age group 15-34. The estimates of the under-five mortality for Zimbabwe exhibit a similar pattern.

We summarize the results of both applications of the own-child method in Figure 4.1 below. The series denoted $q(a)Eqtn$ and $q(a)Eqtn-Corrected$ are, respectively, the unadjusted and adjusted estimates of childhood mortality derived from the application of the fundamental equation of the own-child method. The series $q(a)PP$ and $q(a)PP-Corrected$ represent, respectively, the unadjusted and adjusted estimates of childhood mortality derived from the application of the approach proposed by Preston and Palloni (1977). As expected, correcting for the bias due to HIV induces an upward adjustment to the estimates of the infant and the under-five mortality.

Figure 4.1 Childhood mortality, fundamental equation and the Preston and Palloni approach, Lesotho DHS 2009



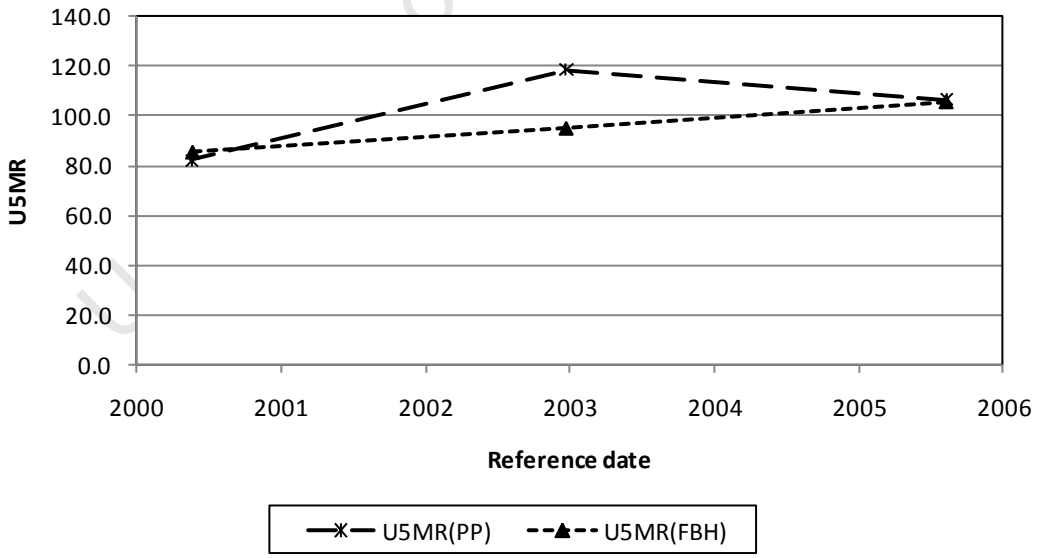
Generally, the estimates of childhood mortality from the method by Preston and Palloni (1977) are more volatile than those derived from the fundamental equation of the own-child method. If the inconsistent estimates of q_0 and $_5q_0$ are disregarded, the other estimates of childhood mortality from the method by Preston and Palloni (1977) are slightly higher than those from the basic equation of the own-child method. The method proposed by Preston and Palloni (1977) relies on two indices of the age distribution of surviving children. These are, the mean age nearest birthday of surviving children, $A_s(i)$, and the proportionate age distribution of surviving children aged below 3 nearest birthday, $c_2(i)$. The estimates of childhood mortality from this application of the method are probably higher because they rely in part on $c_2(i)$, and most children at the young ages are subject to high mortality risks. In contrast, the estimates of childhood mortality derived from the fundamental equation of the own-child method

rely on $c_s(a)$, the proportionate age distribution of surviving children in the age range 1-15 years nearest birthday. Thus, most of these children have gone through the early years of life where the risk of mortality is high. The results for Zimbabwe follow the same general pattern (Figure G1, Appendix G).

The estimates derived from the fundamental equation of the own-child method depict a gradual increase in mortality with increasing age of the child. However, the age pattern of the mortality rates from the fundamental equation depends solely on the family of the Princeton model life table that was used to solve the equation, rather than the pattern inferred by reports by women in different age groups.

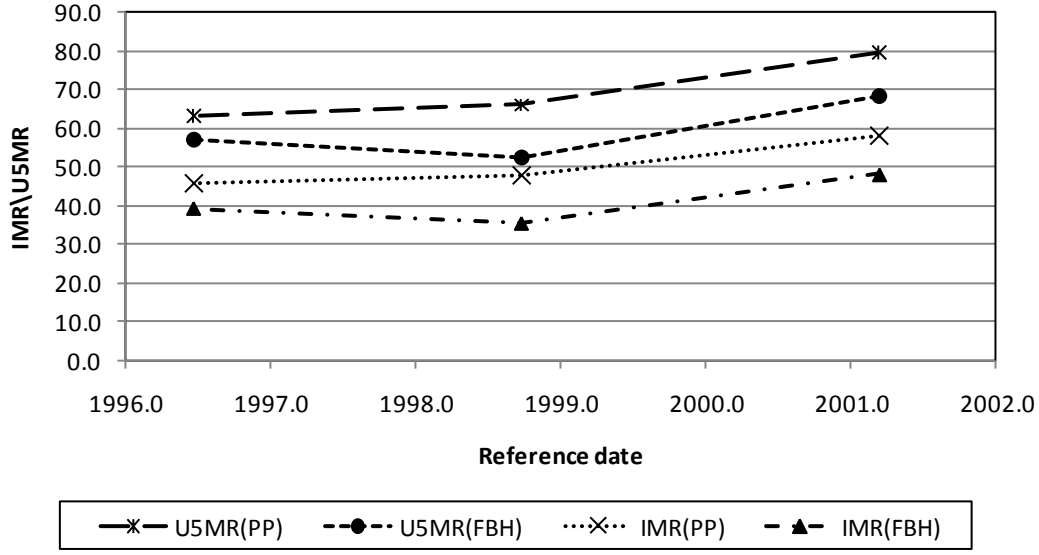
Figure 4.2 presents the indirect and the direct estimates of the under-five mortality that we use to derive the estimates of the bias in ${}_5q_0$, as described in Section 3.6. The series $U5MR(PP)$ and $U5MR(FBH)$ represent, respectively, the indirect estimates of the under-five mortality derived from the application of the approach proposed by Preston and Palloni (1977) and the corresponding direct estimates derived using the full birth history data.

Figure 4.2 Under-five mortality (${}_5q_0$), from the direct method and the Preston and Palloni approach, Lesotho DHS 2009



The indirect estimates of the under-five mortality are generally greater than the direct estimates. The results for Zimbabwe presented in Figure 4.3 clearly show that the indirect estimates of the infant and the under-five mortality are all greater than the corresponding direct estimates.

Figure 4.3 Infant and Under-five mortality, from the direct method and the Preston and Palloni approach, Zimbabwe DHS 2005-6

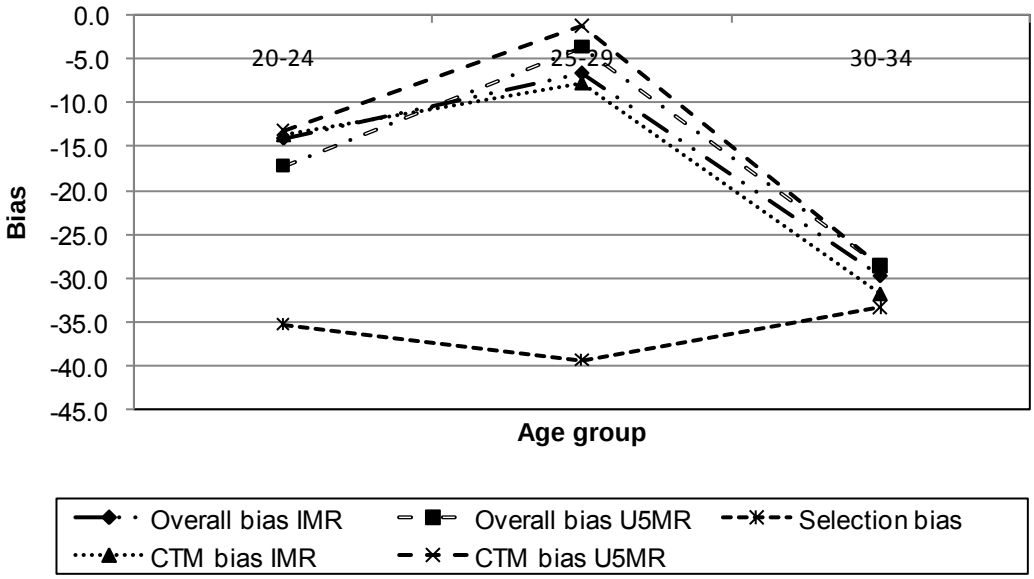


The discrepancy between the indirect and the direct estimates suggests that there is a bias inherent in the own-child indirect method relative to the direct method of estimating childhood mortality using full birth history data. Given that this relative methodological bias occurs in the absence of HIV/AIDS, the interpretation of the estimates of the bias in the own-child method due to HIV/AIDS presented in Section 4.3 that follows is mindful of the confounding effect of this bias.

4.3 Estimates of the bias in the own-child method due to HIV/AIDS

The estimates of the overall bias, the selection bias, the coefficient and timing bias, and the relative methodological bias (*CTM*), are given in Figure 4.4.

Figure 4.4 Overall bias, selection bias, coefficient and timing bias, and the relative methodological bias, Lesotho DHS 2009



The magnitude of the underestimation of childhood mortality induced by the selection bias is high in comparison to the combined bias due to the coefficients and timing, and the relative methodological bias (denoted on the graph as *CTM*). In particular, the relative methodological bias offsets the contribution of the selection bias to the overall bias. Thus, the interpretation of the impact of the overall bias due to HIV/AIDS on the own-child method is confounded by the contribution of the relative methodological bias. Although the overall bias leads to the underestimation of the estimates of the childhood mortality, its impact appears to be diminished. For Zimbabwe, we find the same interplay between the three types of bias (Figure H1, Appendix H).

The underestimation induced by the overall bias in the estimates of the infant and the under-five mortality rates of both Lesotho and Zimbabwe is at its maximum for the estimates that are derived from the reports of women in the oldest age group, 30-34. This is probably because women in this oldest age group are subject to an increased cumulative risk of HIV infection and mortality before the time of the survey. Related to this, vertical transmission of HIV from mother to child occurs mostly to women in the age group 20-24, because childbearing and the incidence of HIV is highest for this age group (Ward and Zaba 2008). Thus, the overall bias is at its maximum roughly five to ten years later when the cohort of women is subject to the highest AIDS mortality (Ward and Zaba 2008). Another reason could be that the problem of the displacement of births of women aged 30-34 that resulted in an abnormally low estimate of the under-

five mortality rate (Section 4.2) increases the discrepancy between the indirect estimates of the infant and under-five mortality rates and the corresponding direct estimates for this age group.

The effect of the relative methodological bias makes it difficult to draw conclusions about the differential impact of the overall bias on the estimates of the infant and the under-five mortality rates for Lesotho. For Zimbabwe, the underestimation induced by the overall bias is greater for the under-five than the infant mortality rate. This is probably a result of the increased cumulative risk of HIV infection and death before the interview of older women with births further back in time.

The results for both countries indicate that the underestimation of childhood mortality due to the selection bias is at its maximum for the estimates that are derived from the reports of women in the age group, 25-29. Again, this is the result of the combination of high childbearing and incidence of HIV and the subsequent increase in the vertical transmission of HIV from mother to child, among this cohort of women, five years earlier. Thus, women aged 25-29 are subject to some of the highest AIDS mortality before or around the time of the survey.

Table 4.2 presents, as percentages, the overall and selection bias due to HIV/AIDS in the estimates of childhood mortality for Lesotho and Zimbabwe.

Table 4.2 Overall and selection bias (%), Lesotho 2009 DHS and Zimbabwe DHS 2005-6

	Overall bias (%)				Selection bias (%)	
	Lesotho		Zimbabwe		Lesotho	Zimbabwe
Age group of women (*i*)	IMR	U5MR	IMR	U5MR		
20-24	-15.2%	-13.9%	7.3%	-2.1%	-27.7%	-15.0%
25-29	-7.1%	-2.9%	8.7%	-6.2%	-26.4%	-27.5%
30-34	-33.2%	-25.8%	-15.1%	-23.5%	-28.9%	-21.5%

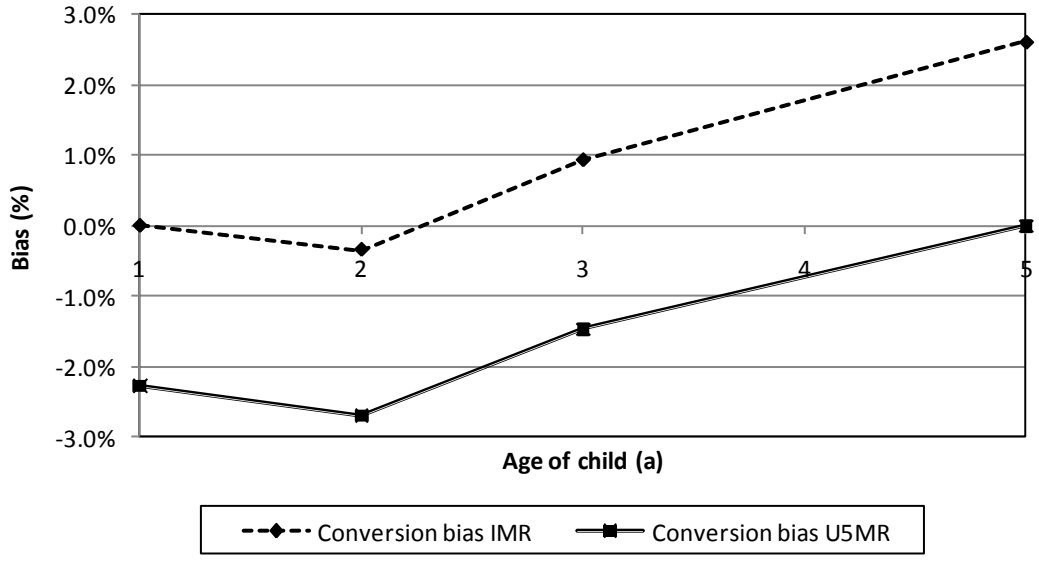
Generally, the magnitude of the overall bias introduced by HIV/AIDS into the estimates of childhood mortality falls outside the 5 per cent range. As mentioned earlier, the interpretation of the significance of the impact of the overall bias due to HIV/AIDS on the estimates of childhood mortality is confounded by the contribution of the relative methodological bias. The estimates of the selection bias are all negative and undoubtedly outside the 5 per cent range for all the age groups, 20-24, 25-29 and 30-34. Thus, HIV/AIDS produces a significant underestimation of the estimates of childhood mortality from the normal application of the method by Preston and Palloni (1977) derived from the reports of women in these age groups. We note though that the

estimates of the selection bias are probably high. There are uncertainties regarding the accuracy of the adjusted estimates of the childhood mortality from the method by Preston and Palloni (1977) that are used to derive the selection bias for each of these age groups of women. This is because the quadratic curves of the selection bias that we used to adjust the data for women in these age groups did not provide an adequate fit to the data (see Figure C3, C4 and C5, Appendix C).

The estimates of the selection bias derived using the 1988 Zimbabwe DHS data (Figure H3, Appendix H) are lower in comparison to those derived using the 2005-6 DHS data. This probably indicates that the magnitude of the selection bias increases during the course of the HIV/AIDS epidemic. The 1988 Zimbabwe DHS results also indicate that the magnitude of the selection bias produces a significant underestimation of the estimates of childhood mortality derived using the reports of women in the age groups 20-24 and 30-34.

The bias introduced by the use of the Princeton model life tables as the standard tables to convert the estimates of childhood mortality to common indices of mortality, q_0 and ${}_5q_0$, rather than a table which reflected the impact of HIV on mortality, is presented in Figure 4.5.

Figure 4.5 Conversion bias due to the use of the Princeton model life tables, Lesotho DHS 2009



The underestimation resulting from the use of the Princeton model life tables that do not account for HIV/AIDS is greater for the under-five than the infant mortality rate because of the increased cumulative risk of HIV infection and death before the interview of older women with births further back in time. Figure H.2 in

Appendix H shows that the conversion bias produces a similar effect on the estimates of the infant and under-five mortality rates for Zimbabwe. The results for the 1988 ZDHS presented in Figure H.4 of Appendix H also confirm that the conversion bias is greater for the under-five than the infant mortality rate.

The magnitude of the underestimation of the infant and the under-five mortality rates is at its maximum at the age of two, corresponding to the estimates that are derived from the reports of women in the age group 20-24. Again, this is probably a result of the high childbearing among women in the young age groups. The mortality of the births of young women who are HIV positive is under-represented at the time of the survey because of the death of their HIV positive mothers. Although the inappropriate use of the Princeton model life tables in HIV/AIDS contexts induces a downward bias in the estimates of the under-five mortality rate, particularly at the ages one to four years, the bias is less than 5 per cent.

The difference between the overall bias and the conversion bias is a mixture of the coefficient and timing bias, and the bias inherent in the method that exists in the absence of HIV/AIDS. The effect of the coefficient and timing bias is probably insignificant (Chitiyo 2011). Thus, the remaining significant source of bias, though non-HIV/AIDS related, is the relative methodological bias that overestimates the infant and the under-five mortality rate (Adetunji 1996).

5 DISCUSSION AND CONCLUSIONS

5.1 Introduction

This study sought to estimate and understand the bias due to HIV/AIDS in the estimates of the infant and under-five mortality rates derived using the own-child method. In addition, we sought to derive the target estimates of the infant and under-five mortality rates in order to estimate the extent of the overall bias and component biases in the own-child method due to HIV/AIDS in Lesotho and Zimbabwe. This chapter reflects on the extent to which the study findings meet the research objectives and what conclusions can be drawn from the research. Section 5.2 discusses the estimates of childhood mortality from the own-child method and the best estimates of mortality derived directly from the data on full birth histories of women corrected for the bias due to HIV, which is used to derive the bias due to HIV/AIDS. Section 5.3 looks at the bias in the own-child method due to HIV/AIDS obtained. Section 5.4 gives the limitations of the study. Finally, section 5.5 gives the conclusions drawn from the study and recommends areas for further research.

5.2 Estimates of childhood mortality from the own-child method and the direct method

The two variations of the own-child method that we applied give slightly different levels of childhood mortality. The estimates from the method proposed by Preston and Palloni (1977) are marginally higher than those derived on the basis of the fundamental equation of the own-child method. We used the former estimates to derive the bias in the own-child method due to HIV/AIDS, notwithstanding the instability of these estimates caused by the relatively fewer observations obtained when women are classified into five-year age groups as opposed to the broad 15-34 year age group used to derive the latter estimates.

The target estimates of the infant and the under-five mortality rate were derived by adjusting the direct estimates from the full birth history for the selection bias introduced by HIV/AIDS using the correction factors produced by the workbook prepared by Hill and Walker (personal communication with K. Hill. 2011). These correction factors are specifically designed to adjust for the selection bias introduced by HIV/AIDS into the direct estimates of the under-five mortality rate. To calculate the deaths of the children who are HIV positive that occur before the age of one, the workbook was adapted by, *inter alia*, making use of the mortality rates from an

associated single decrement life table for HIV positive births that is designed to estimate mortality under the age of five. Thus, the reliability of our target estimates of the infant mortality rate is compromised because the single decrement life table may provide inaccurate mortality rates for the first year of life of the HIV positive births since that was not its original purpose, although this limitation is not expected to be very significant.

The study also derived the target estimates of the infant mortality rate based on the assumption that the births to HIV positive mothers occur on average to the mothers four years after infection, the same assumption used in deriving the target estimates of the under-five mortality rate. Again, the reliability of our target estimates of the infant mortality rate may be compromised because the assumption may not apply to women reporting about the deaths of their children who die before the age of one.

Finally, the assumption in this study that the adjusted direct estimates of the infant and under-five mortality rates provide accurate estimates that can be used as the yardstick for measuring the bias in the own-child method due to HIV/AIDS is also problematic. There could be some data errors in the direct estimates caused by the misreporting of dates of birth, ages at death or selective recall.

5.3 Bias in the own-child method due to HIV/AIDS

Any attempt to validate the external consistency of the childhood mortality estimates from both variations of the own-child method is hindered by the lack of studies in Lesotho and Zimbabwe that apply the method to estimate childhood mortality, let alone to determine the impact of HIV/AIDS on the method. Consequently, regarding the estimates of the bias, we compare our findings with those from other studies that estimated the bias in the direct method and the Brass CS/CEB technique.

The study findings confirm that the bias introduced by HIV/AIDS due to the selection of women who survive to be interviewed leads to the underestimation of childhood mortality. However, the intrinsic bias of the own-child indirect method relative to the direct method induces a significant upward bias in the estimates of childhood mortality, independently of HIV/AIDS. This relative methodological bias negates, to a large extent, the contribution of the selection bias to the overall bias. Thus, the impact of the overall bias due to HIV/AIDS on the own-child method, though significant, is diminished.

Given that the incidence of HIV reaches a peak for women in the age group 20-24, the magnitude of the overall bias for both Lesotho and Zimbabwe is as expected,

highest for women aged 30-34 because the cohort of women is subject to the highest AIDS mortality roughly ten years later. For Zimbabwe, the results of this research are consistent with the findings by Hallet, Gregson, Kurwa *et al.* (2010), which also show that the bias due to HIV/AIDS is greater for the under-five than the infant mortality rate. This is to be expected, because older women, with births further back in time, are subject to an increased cumulative risk of HIV infection and death before the interview. However, for Lesotho, it is difficult to draw meaningful conclusions about the differential impact of the overall bias on the estimates of the infant and the under-five mortality rates because of the effect of the relative methodological bias. It should be noted that Hallet, Gregson, Kurwa *et al.* (2010) estimate the extent of the bias due to HIV/AIDS in the direct estimates, whereas we estimate the bias in the indirect estimates of the infant and under-five mortality rates from the own-child method. In the context of an HIV/AIDS epidemic three assumptions of the own-child method are violated in contrast to one for the direct method. Thus, one needs to compare these results with the findings by Hallet, Gregson, Kurwa *et al.* (2010), mindful that HIV/AIDS impacts the direct and the indirect method used in this study differently.

The estimates of the selection bias in the childhood mortality rates derived in this research from the reports of women in the age groups, 20-24, 25-29 and 30-34 exceed the 5 per cent threshold, and are therefore significant. This result is expected given the high rate of HIV prevalence of 23.6 per cent and 14.3 per cent in Lesotho and Zimbabwe, respectively (UNAIDS 2010). The analyses by Ward and Zaba (2008) reveal that the bias introduced by HIV/AIDS in the unadjusted estimates of childhood mortality derived from the reports of women in these age groups is significant if the HIV prevalence exceeds 4 per cent. In relating our findings to those by Ward and Zaba (2008), we are cognizant that their work is an analyses of the extent of the bias introduced by HIV/AIDS in the estimates of childhood mortality derived using the Brass CS/CEB method rather than the own-child method. However, we expect the impacts of HIV/AIDS on the Brass CS/CEB method to be similar to its impacts on the own-child method, on the assumption of constant prevalence of HIV, because both methods rely on the summary birth history data and the assumptions required to apply both of them are similar.

Again, this result is consistent with the findings from the 1988 Zimbabwe DHS indicating that by that time, the effect of the selection bias on the estimates of childhood mortality was already significant (Figure H3, Appendix H). However, the

results for the 1988 ZDHS are rather unexpected and inconsistent with the findings by Hallet, Gregson, Kurwa *et al.* (2010) that indicate that the selection bias became significant by the late 1990s. Given that the estimates of the selection bias derived using the 1988 ZDHS data are lower than those derived using the 2005-6 DHS data, the magnitude of the selection bias increased during the course of the HIV/AIDS epidemic in Zimbabwe. This is consistent with the findings by Hallet, Gregson, Kurwa *et al.* (2010) that also indicate that the extent of the selection bias increased as the HIV/AIDS epidemic grew in Zimbabwe. .

It should be noted, though, that there is uncertainty surrounding the accuracy of the adjusted estimates of the childhood mortality from the method by Preston and Palloni (1977) that we used to derive the selection bias for each of the age groups of women. Undoubtedly, the quadratic curves fitted to the selection bias by age of children that we used to adjust the data for women in the age groups 20-24, 25-29 and 30-34 did not provide an adequate fit to the data.

The study constructed a period life table from a SPECTRUM projection that incorporates the effect of the HIV/AIDS epidemic. Using this table as the standard, we confirmed that although the use in high HIV prevalence settings of the Princeton model life table leads to the underestimation of the under-five mortality rate, the underestimation due to this is not large. Nonetheless, in the context of an HIV/AIDS epidemic, the accuracy of the indirect estimates of childhood mortality can still be enhanced by using model life tables that incorporate the impact of HIV/AIDS. Although the INDEPTH model life tables can be used for this purpose, they have their limitations. One of them is that they are abridged and therefore do not provide life table survival probabilities for the child ages two up to four years. Thus, the use of the INDEPTH model life tables requires first estimating the life table survival probabilities for the child ages two up to four years. The study could not use the INDEPTH model life tables specifically because of this limitation.

Although we managed to tease out the contribution to the overall bias of the selection and conversion biases, we could not estimate the residual coefficient and timing bias. Any attempt to estimate the effect of the coefficient and timing bias would be confounded by the significant influence of the relative methodological bias. We could only assume, based on the findings from a similar study by Chitiyo (2011) considering the bias in the estimates produced by the Brass CS/CEB method, that the coefficient and timing bias is insignificant.

5.4 Limitations of the study

It is difficult to draw firm conclusions from our findings regarding the overall bias due to HIV/AIDS in the estimates of childhood mortality produced by the own-child method because of the influence of the intrinsic bias of the own-child indirect method relative to the direct method. The evaluation of the data did not reveal any serious defects to invalidate their use in the indirect estimation of childhood mortality using the own-child method. However, the study could not assess the extent of the data errors in the direct estimates caused by the misreporting of the dates of birth, ages at death or selective recall. Thus, there is some doubt surrounding the reliability of our target estimates of the infant and under-five mortality rates. Moreover, the study relied on adjusted direct estimates of the infant mortality rate, based on a crude adaptation of the workbook by Hill and Walker. This casts further doubt on the reliability of our target estimates of the infant mortality rate.

Although we can infer the impact of the selection bias induced by HIV/AIDS, uncertainties surround the accuracy of the adjusted estimates of the childhood mortality from the method by Preston and Palloni (1977) that we used to derive this bias. The quadratic curves of the selection bias used to adjust the data for the five-year age groups of women did not provide an adequate fit. Besides, the accuracy of the unadjusted estimate of the under-five mortality rate for Lesotho derived from the reports of women aged 30-34 is compromised by the problem of birth displacement. Thus, our estimates of the selection bias are probably high and it is difficult to judge whether these true values are actually large.

5.5 Conclusions

The study applied the own-child method to estimate child mortality in Lesotho and Zimbabwe. In the process, we demonstrated using the 2006 Lesotho census data, the potential of the software, MATCHTAB, to link successfully surviving children to their biological mothers. The research derived the estimates of childhood mortality for Lesotho and Zimbabwe using two variations of the own-child method. The estimates from the method proposed by Preston and Palloni (1977) can be utilized to estimate the variation of the bias due to HIV/AIDS by the child ages. However, the problem of birth displacement in demographic and health surveys affects the estimate of the under-five mortality rate derived from the method proposed by Preston and Palloni (1977). The accuracy of this estimate is compromised by the problem of birth displacement because it is derived from the reports of women aged 30-34. Their births occur on

average five years before the survey and are therefore likely to be transferred by interviewers to the sixth calendar year. To produce better estimates of the under-five mortality rate using the method proposed by Preston and Palloni (1977), future research should apply the method to census data.

The work by Hill and Walker should also be extended in order to provide direct estimates of the infant mortality rate that are adjusted for the bias due to HIV/AIDS. This can be done by calculating the deaths of the children who are HIV positive that occur before the age of one using the mortality rates from an associated single decrement life table for HIV positive births that is designed to estimate mortality under the age of one. Assumptions that specifically relate to the calculation of the bias due to HIV/AIDS in the direct estimates of the infant mortality rate should be formulated.

The study findings reveal that the overall bias in the own-child method due to HIV/AIDS is significant, thus child mortality estimates derived from the method should be adjusted for this bias. The results also indicate that the selection of women who survive to be interviewed induces a significant downward bias in the estimates of childhood mortality. However, it is difficult to verify the reasonableness of the estimates of the selection bias introduced by HIV/AIDS into the own-child method. Thus, further research could focus on deriving correction factors required to calculate and adjust for the selection bias in the own-child method akin to the work done by Ward and Zaba (2008) with respect to the Brass CS/CEB technique. In the absence of such correction factors, the estimates of childhood mortality from the own-child method should not be used to inform policy in countries that are heavily affected by the HIV/AIDS epidemic. The development of the correction factors also facilitates the comparison of the selection bias in the own-child method with the selection bias introduced by HIV/AIDS into the Brass CEB/CS method. Thus, research in future will be able to assess the robustness of the indirect methods of estimating childhood mortality in the era of HIV/AIDS.

The increased provision of antiretroviral therapy (ART) occurring in countries of sub-Saharan Africa (UNAIDS 2010) is expected, with time, to reduce the selection bias in the own-child method due to HIV/AIDS because of the subsequent decrease in AIDS mortality among HIV infected mothers and their children. Moreover, the selection bias is expected to decrease gradually as the risk of mother-to-child transmission of HIV is reduced because of an increase in the prevention of mother-to-

child transmission (PMTCT) programs that is also occurring in countries of sub-Saharan Africa (UNAIDS 2010).

Even though the conversion bias results in the underestimation of the under-five mortality rate, the underestimation is not significant. Rather, we have shown that the selection bias could be contributing significantly to the overall bias. Thus, the impact of HIV/AIDS on the own-child method cannot be addressed adequately by only replacing the Princeton model life tables with standard tables that account for the HIV/AIDS epidemic, as the study by Opiyo (2009a) suggests. Again, further research should focus mainly on mitigating the significant impact of the selection bias.

In countries with a high prevalence of HIV/AIDS, the INDEPTH model life tables can be used as the standard tables to convert the estimates of childhood mortality to common indices of infant and under-five mortality. However, these model life tables are abridged and therefore do not provide life table survival probabilities for the child ages two up to four years. There is a need for the development of model life tables that incorporate the impact of the HIV/AIDS epidemic and at the same time provide the pattern of childhood mortality by single ages.

This study could not estimate the effect of the coefficient and timing bias because of the confounding influence of the relative methodological bias. Thus, further research is needed to examine the extent of the bias in the own-child method that is introduced by the use of the regression coefficients for multipliers and the time location estimates that were derived from simulations that do not consider HIV/AIDS.

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Appendix A. Data quality

Figure A.1 Percentage distribution of the child population by age in single years, Zimbabwe DHS 2005-6

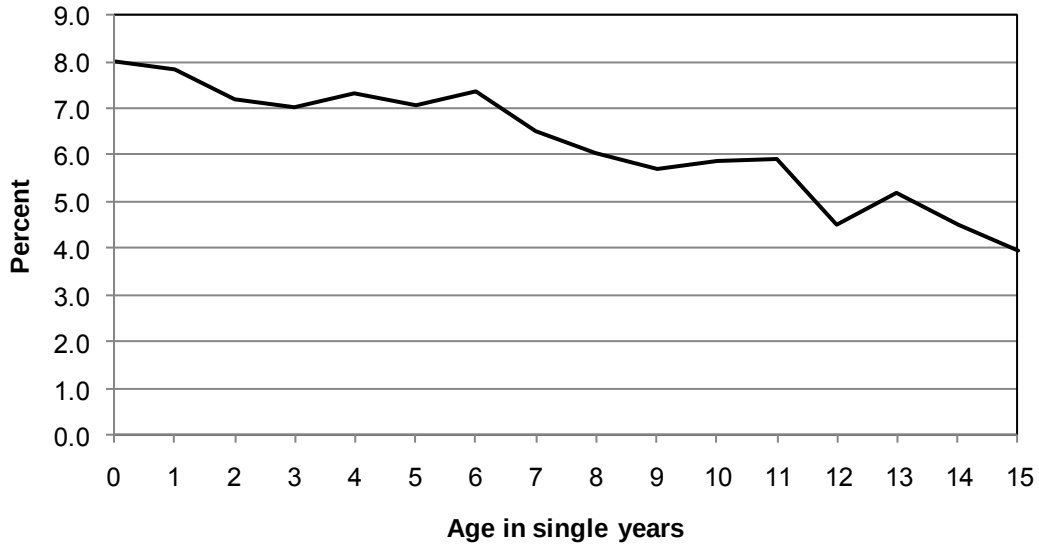


Figure A.2 Percentage distribution of the child population by grouped age, Zimbabwe DHS 2005-6

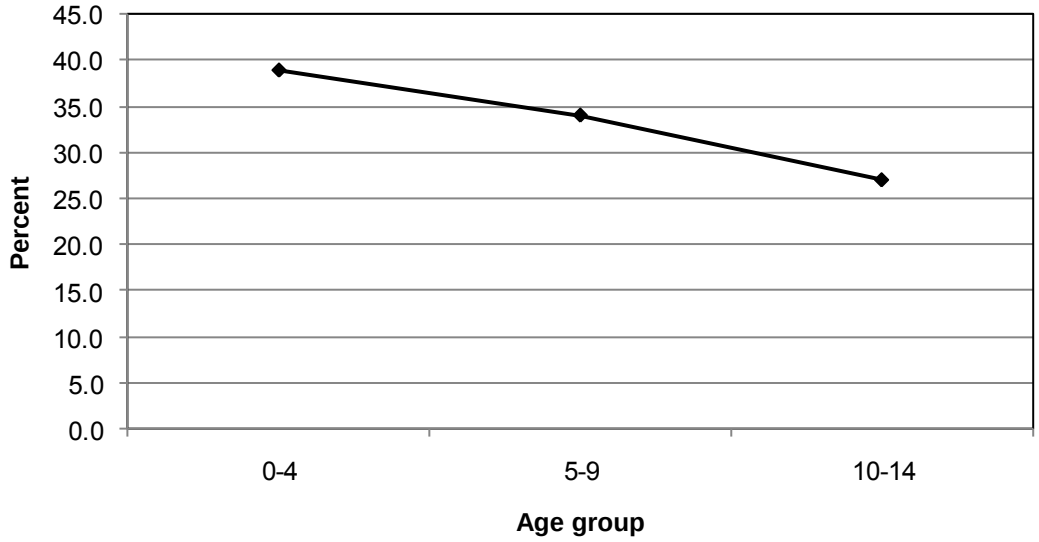


Figure A.3 Percentage age distribution of women aged 15-49, Zimbabwe DHS 2005-6

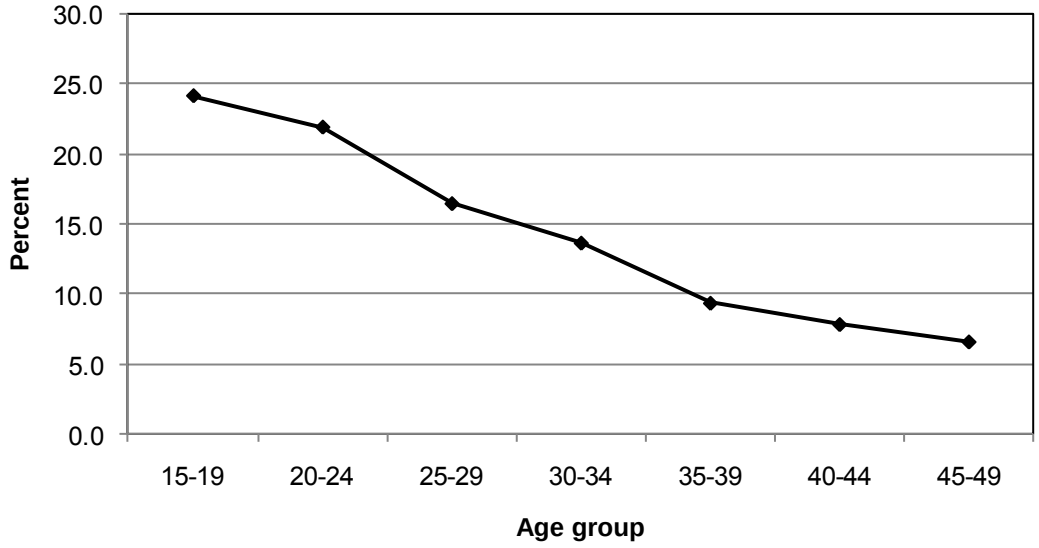


Figure A.4 Average parities of women aged 15-49, Zimbabwe DHS 2005-6

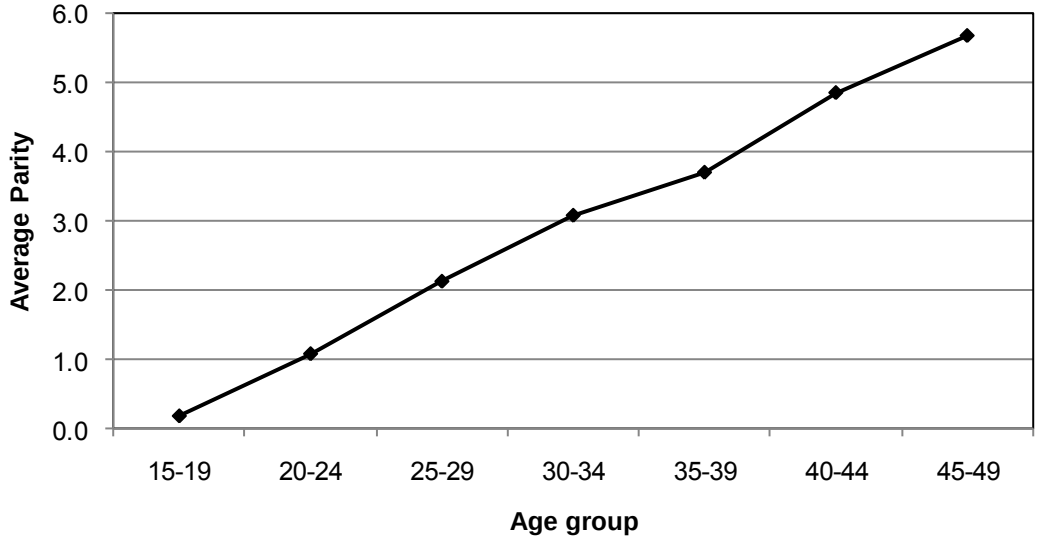


Figure A.5 Proportions of children reported dead by women aged 15-49, Zimbabwe DHS 2005-6

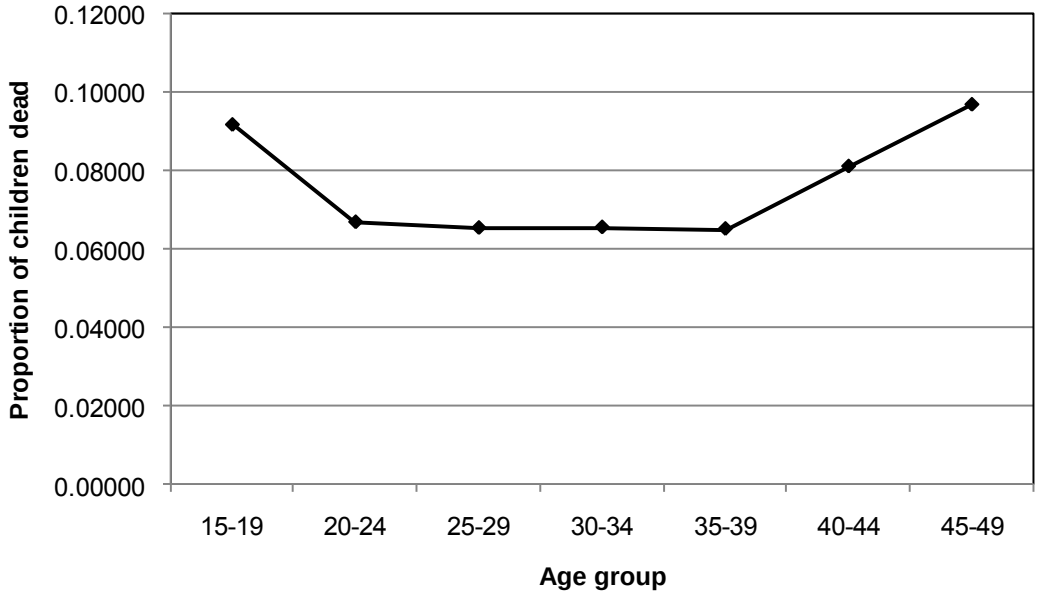


Table A.1 Sex ratios of children ever born to women aged 15-49, Zimbabwe DHS 2005-6

Age group	Children ever born		Sex Ratio
	Male	Female	
15-19	204	175	116.7
20-24	1068	1034	103.3
25-29	1617	1500	107.8
30-34	1903	1843	103.2
35-39	1512	1578	95.8
40-44	1761	1635	107.7
45-49	1657	1689	98.1
Overall	9720	9453	102.8

Table A.2 Birth-year ratios of all children, surviving children and dead children, Zimbabwe DHS 2005-6

Year	All children	Surviving children	Dead children
1991	100.3	98.1	133.0
1992	109.6	111.7	85.0
1993	82.6	81.9	93.9
1994	115.7	116.7	101.7
1995	100.6	99.8	112.4
1996	94.1	93.8	97.8
1997	102.4	102.7	98.1
1998	93.2	94.1	78.5
1999	110.4	110.8	104.7
2000	99.4	98.1	116.9
2001	96.6	96.6	96.2
2002	101.8	102.9	88.2
2003	98.4	96.5	123.3
2004	108.8	108.6	111.9

Appendix B. The Hill and Walker workbook

The workbook by Hill and Walker (personal communication with K, Hill 2011) is a tool for calculating and adjusting for the selection bias introduced by HIV into the direct estimate of the under-five mortality rate derived from full birth history data because of their sole reliance on reports of mothers who survive to the time of the survey. The input required for the procedure for estimating bias are, a SPECTRUM projection of the country's annual number of births and the annual HIV prevalence among pregnant women in the age range 15-49. The following input data are also required: an assumed mother-to-child HIV transmission rate of 35 per cent; and the West family of the Princeton model life tables with the level of the under-five mortality rate chosen to be approximately equal to that of the HIV negative population. The method for estimating the bias also requires, an associated single decrement life table, excluding deaths due to non-AIDS causes of the HIV positive births for ages zero up to five that is fitted on the basis of evidence from cohort studies indicating that 62.5 per cent of HIV positive births die by the age of five. Further, the method uses a survival function from four years after infection with HIV to the year of any given survey that is generated from a survival function from first infection of females with a median survival time of 9.5 years. These input data are in the worksheet named "Base values".

For each of the years before a given survey, the HIV prevalence among pregnant women in the year of birth is used to apportion the births to HIV positive and HIV negative women. Hill and Walker assume that all of the births to HIV negative women are HIV negative. The workbook uses an assumed mother-to-child HIV transmission rate of 35 per cent to subdivide the births to HIV positive women by HIV status. Thus, for any given level of the under-five mortality rate, for example, 50 deaths per 1,000 live births, there are three categories of births. In the first category are HIV negative births that are born to HIV negative mothers, calculated by multiplying the births in a given year by the complement of the HIV prevalence among pregnant women for that year. The second category consists of HIV negative births that are born to HIV positive mothers, calculated by multiplying the births in a given year by the HIV prevalence among pregnant women for that year and the complement of the mother-to-child HIV transmission rate. The third category consists of HIV positive births that are born to HIV positive mothers, calculated by multiplying the births in a given year by the HIV prevalence among pregnant women for that year and the mother-to-child HIV transmission rate. The data pertaining each of these three categories of births are in the

worksheets, "HIV Neg U5MR 50", "HIV Pos Neg U5MR 50" and "HIV Pos Pos U5MR 50" respectively.

The worksheets "HIV Neg U5MR 50" and "HIV Pos Neg U5MR 50" also provide respectively, the deaths that occur before each of the ages from zero up to the age of five during any given year before a survey to the HIV negative births that are born to HIV negative and HIV positive mothers. These deaths are calculated by multiplying the births in each of the two categories by the age-specific mortality rate from the West family of the Princeton model life tables with the level of the under-five mortality rate estimated in this instance, at 50 deaths per 1,000 live births. The level of the under-five mortality rate is chosen to be approximately equal to that of the HIV negative population. The total under-five deaths during any given year before a survey is the sum of the deaths that occur before each of the ages from zero up to age five. Hill and Walker calculate the deaths that occur to these two categories of birth by assuming that HIV negative children experience the same mortality risks notwithstanding the HIV status of the mother.

Worksheet "HIV Pos Pos U5MR 50" presents the deaths of the children who are HIV positive that occur before each of the ages from zero up to the age of five during any given year before a survey. These deaths are calculated by multiplying the HIV positive births by the age-specific mortality rate from the associated single decrement life table for HIV positive births that is fitted based on evidence from cohort studies indicating that 62.5 per cent of HIV positive births die by the age of five. The total under-five deaths during any given year before a survey is the sum of the deaths that occur before each of the ages from zero up to age five.

Hill and Walker assume that all of the women who are HIV negative survive to report all of their births and the deaths of their children who die before the age of five. To estimate the number of births and deaths to children below the age of five that are unreported in a survey because of the deaths of HIV positive mothers, Hill and Walker formulate two additional assumptions. They first assume that the births to HIV positive mothers occur on average to the mothers four years after infection. They justify the choice of four years by stating that the fertility of HIV positive women drops by almost a quarter after a period of four years of infection with HIV. They also assume that surveys are conducted at the end of the calendar year. Based on these assumptions, the number of births and deaths before the age of five of both HIV negative and HIV positive children born to HIV positive mothers reported in a survey is then calculated

by multiplying the births and under-five deaths by the conditional probability that an HIV positive woman, infected for four years at the birth of her child, survives from the time of birth to the time of a survey. These reported births and under-five deaths of children born to HIV positive mothers are added to the births and the under-five deaths of children born to HIV negative mothers to give the reported births and deaths that are presented in the worksheet "Summary U5MR 50". The births and the under-five deaths of HIV negative and HIV positive children born to HIV positive mothers that are not reported in a survey are calculated by multiplying the births and under-five deaths by the conditional probability that an HIV positive woman infected for four years at the birth of her child, dies between the time of birth and the time of a survey. The unreported births and the under-five deaths of HIV negative and HIV positive children born to HIV positive mothers are both presented in the worksheet "Summary U5MR 50".

The true number of births and under-five deaths is then calculated as the sum of the births and deaths that are reported by both HIV positive and HIV negative mothers and those that are unreported by HIV positive mothers. These true births and under-five deaths and the births and under-five deaths reported by both HIV positive and HIV negative mothers are summed for each of the three five-year periods, 0-4, 5-9 and 10-14 years prior to a survey. The extent of the bias in the estimate of the under-five mortality rate for any given five-year period preceding a survey is estimated as the ratio of the reported under-five deaths to the reported births divided by the ratio of the true under-five deaths to the true births. The bias estimates for the four five-year periods, 0-4, 5-9, 10-14 and 15-19 years preceding a survey are calculated in worksheet "Summary U5MR 50". If a survey reveals the problem of birth displacement, described in section 3.3.5, the worksheet also provides the calculations of the bias estimates for the four five-year periods, 1-5, 6-10, 11-15 and 16-20 years preceding the survey.

Thus, the adjusted estimate of the under-five mortality rate is obtained by dividing the survey estimate for a given five-year period preceding a survey by the bias for the corresponding period. The adjustment of the survey estimate of the under-five mortality rate for each of the five-year periods preceding a survey for the selection bias introduced by HIV is performed in the worksheet "Corrected U5MR".

The workbook by Hill and Walker is designed to calculate and adjust for the selection bias introduced by HIV into the direct estimate of the under-five mortality

rate. We calculated estimates of the infant mortality rate, adjusted for the selection bias due to HIV by replicating the workbook as follows.

The study calculated estimates of the infant mortality rate by considering only the deaths that occur before age one to each of the three categories of births during any given year before the survey. Thus, the total number of deaths before the age of one that occur during any given year before the survey is the sum of the deaths that occur before the ages of zero and one. The study calculated these infant deaths using the mortality rates from the associated single decrement life table for HIV positive births that is designed to estimate mortality under the age of five. We note though that this life table may possibly provide inaccurate mortality rates for the first year of life of the HIV positive births since it is not designed for this purpose.

Again, we derived the bias in the estimates of the infant mortality rate based on the assumption that the births to HIV positive mothers occur on average to the mothers four years after infection, the same assumption used in deriving the bias in the under-five mortality rate. The research notes that this assumption may not apply to women reporting about the deaths of their children who die before age one.

Appendix C. Quadratic curves of the bias due to HIV/AIDS

Figure C1 Quadratic curve of the bias due to HIV/AIDS fitted to the birth history data of women aged 15-34, Lesotho DHS 2009

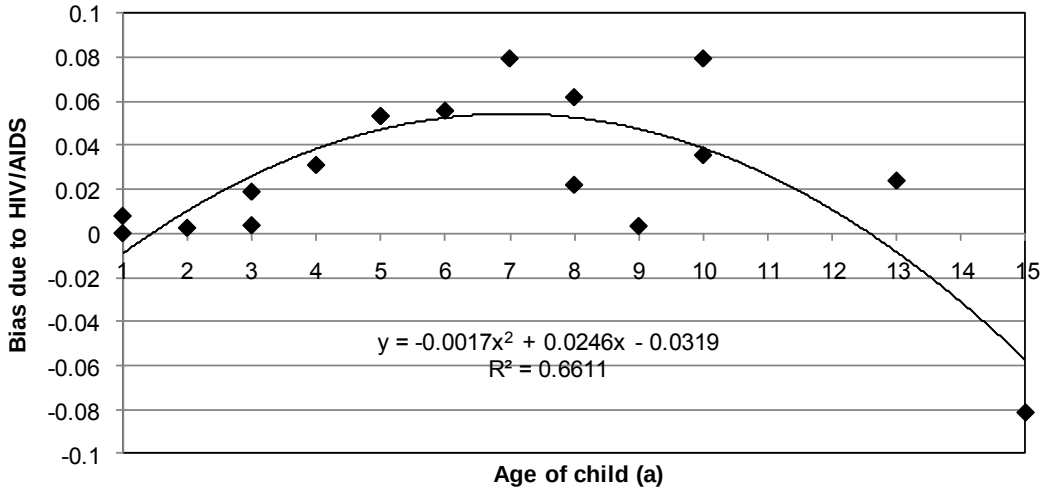


Figure C2 Quadratic curve of the bias due to HIV/AIDS fitted to the birth history data of women aged 15-34, Zimbabwe DHS 2005-6

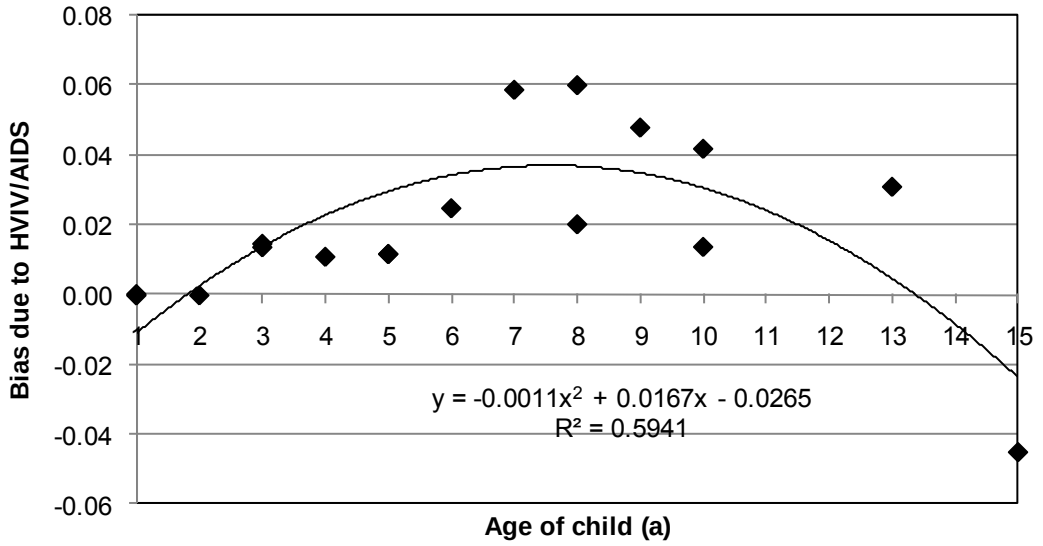


Figure C3 Quadratic curve of the bias due to HIV/AIDS fitted to the birth history data of women aged 20-24, Lesotho DHS 2009

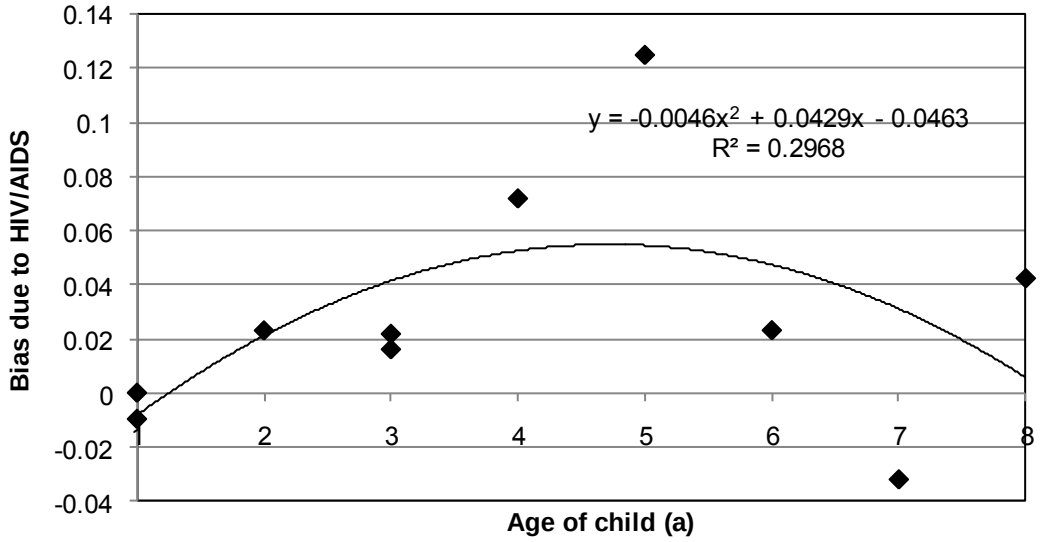


Figure C4 Quadratic curve of the bias due to HIV/AIDS fitted to the birth history data of women aged 25-29, Lesotho DHS 2009

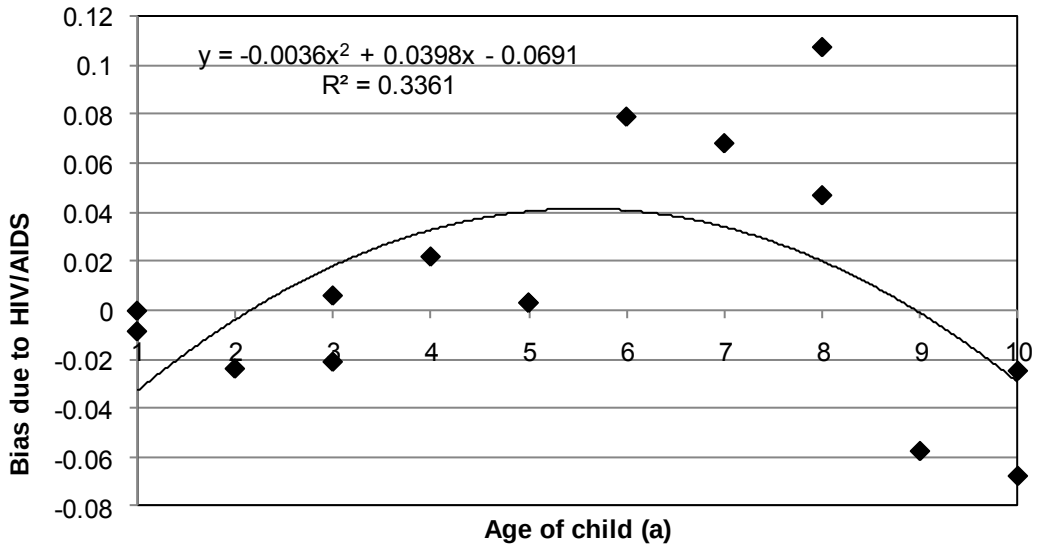
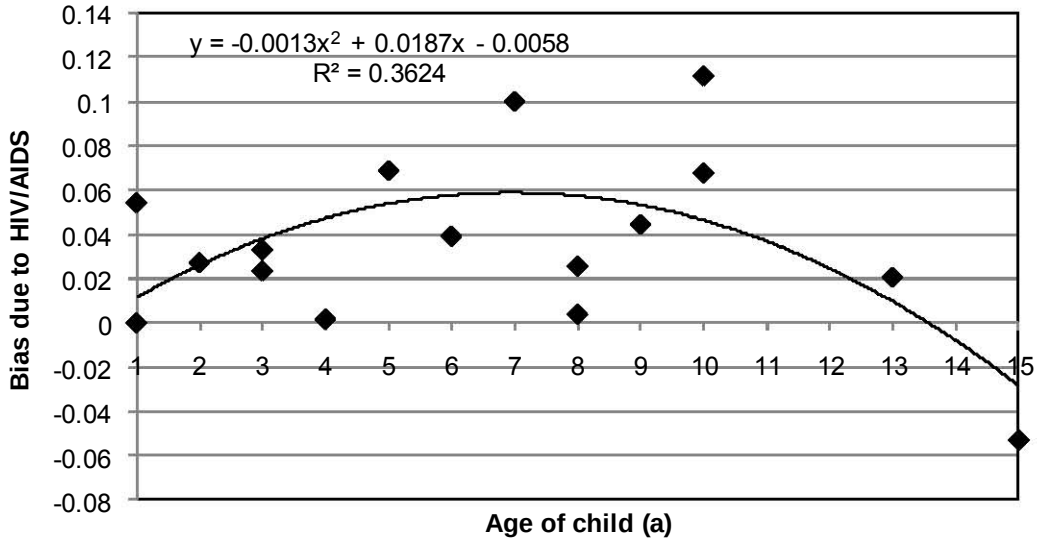


Figure C5 Quadratic curve of the bias due to HIV/AIDS fitted to the birth history data of women aged 30-34, Lesotho DHS 2009



Appendix D. Estimating infant and under-five mortality rates

Appendix D1. Applying the fundamental equation of the own-child method to the data that are unadjusted for the bias due to HIV

We derive the estimates of the infant and the under-five mortality rate that are not adjusted for the bias due to HIV by identifying the level of mortality of the Princeton West model life tables that solves the fundamental equation of the own-child method,

$$\frac{B}{S} = \int_0^{\alpha} \frac{c_s(a)}{p(a)} da \qquad (1)$$

This application of the own-child method requires data regarding the number of births *a* years before the survey that occur during the period $t_s - a - 0.5$ and $t_s - a + 0.5$, $B(t_s - a)$, for *a*=1, 2, 3, . . ., 15, as reported by women in the age range 15-34 years in a survey conducted at time t_s, and the number of those births that survive and are aged *a* nearest birthday at the time of the survey, $S(a)$.

The number of children ever-born to reporting women in the age range 15-34, *B*, is calculated by fitting a linear equation to the number of births that occur *a* years before the survey, $B(t_s - a)$, and the number of years before the survey, *a*, i.e. an equation of the form $B(t_s - a) = \mu + \nu a$. Thus, *B* is calculated using the equation:

$$B = \int_0^{15} B(t_s - a)da = \int_0^{15} (\mu + \nu a)da$$

We then calculate the number of those children ever-born to reporting women in the age range 15-34 that survive to the time of the interview, *S*, by fitting a linear equation to the number of surviving children age *a* nearest birthday at the time the survey, $S(a)$, and their ages at the time of the survey, *a*, i.e. an equation of the form $S(a) = \varphi + \gamma a$. Thus, *S* is given by: $S = \int_0^{15} S(a)da = \int_0^{15} (\varphi + \gamma a)da.$

The left hand side of equation (1) is calculated as the ratio $\frac{B}{S}$ and the proportion of surviving children who are aged *a* nearest birthday at the time of the survey, $c_s(a)$, is estimated as: $c_s(a) = \frac{S(a)}{S}$.

Assuming that the pattern of mortality in Lesotho and Zimbabwe is best represented by the West family of the Princeton model life tables that are combined

using a sex ratio at birth of 1.02, model life table values of $l(a)$ for the ages *a*= 6, 7, 8 and 9 are calculated by fitting to the ages of children, the curve of life table survivors, $l(a) = (1+\alpha a)^{-\beta}$, proposed by Blacker and Brass (2005) using the tabulated values of $l(5)$ and $l(10)$ to solve for α and β. The model life table values of $l(a)$ for *a*=11, 12, 13 and 14 are calculated by linear interpolation between the tabulated values of $l(10)$ and $l(15)$. For a life table with a radix of 1, $l(a) = p(a)$.Thus, equation (1) can be written as: $\frac{B}{S} = \int_0^{\alpha} \frac{c_s(a)}{l(a)} da$ (2)

We identify the set of the model $l(a)$ values that satisfy equation (2) by trial and error. This is done by first fitting a linear equation to the values of $\frac{c_s(a)}{l(a)}$ and the child ages, *a*, i.e. an equation of the form $\frac{c_s(a)}{l(a)} = \kappa + \lambda a$. Thus, the right hand side of equation (2) is computed as follows: $\int_0^{15} \frac{c_s(a)}{l(a)} da = \int_0^{15} (\kappa + \lambda a) da.$

The results for Lesotho indicate that the $l(a)$ values that provide the best fit to equation (2) lie between the levels 17 and 18 of the West family of the Princeton model life tables. The level of mortality of the model that solves equation (2) is then calculated by linear interpolation between the levels 17 and 18 using the value of $\frac{B}{S}$ that constitutes the left hand side of equation (2) and the values of $\int_0^{15} \frac{c_s(a)}{l(a)} da$ that are calculated from the model $l(a)$ values for level 17 and 18. The level of the model that solves equation (2) is 17.5. We then calculate the values of $l(a)$ that best fit equation (2) by linear interpolation between the tabulated values of $l(a)$ for the levels 17 and 18, using the levels 17, 17.5 and 18. The corresponding estimates of the life table probabilities of dying by age *a*, $q(a)$ are calculated using the equation $q(a) = 1 - l(a)$. For Zimbabwe, the level of the model that solves equation (2) is 19.3.

Appendix D2. Estimates of B/S, $c_s(a)$ and $q(a)$ derived from; the 2009 LDHS without using MATCHTAB, and the 2006 Lesotho census using MATCHTAB

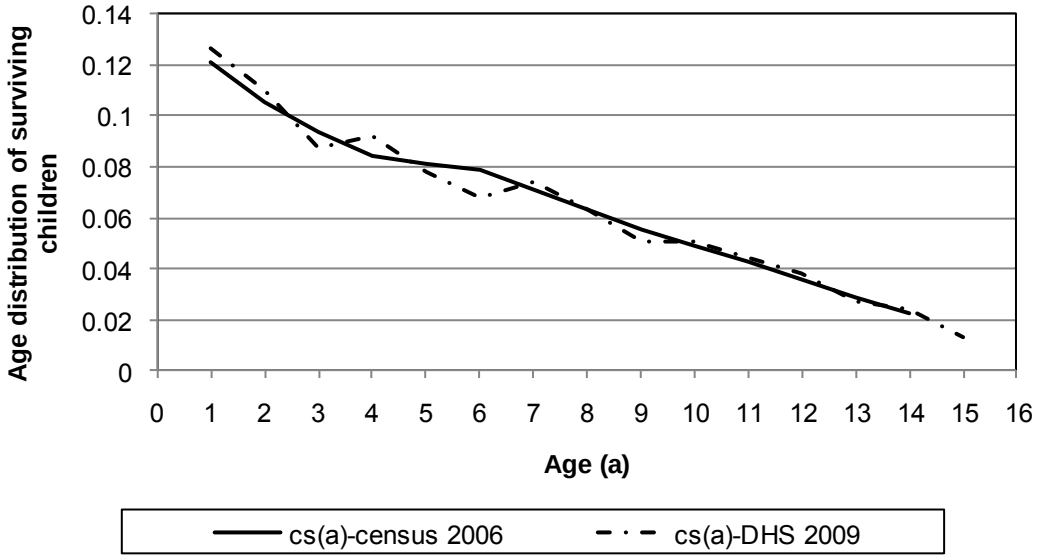
Having derived the estimates of childhood mortality from the 2009 LDHS without using MATCHTAB, we link women enumerated in the 2006 Lesotho census to their biological children using MATCHTAB and demonstrate that we get roughly similar estimates of B/S, $c_s(a)$ and consequently the $q(a)$ values.

We extract the MATCHTAB output data regarding the number of children ever born, children surviving and the mother-child matrix, a tabulation of matched own-children aged 0-14 last birthday by the child's and mother's age both in single years. Next, we compute the ratio B/S using the MATCHTAB output and compare this with the estimate derived from the 2009 Lesotho DHS. The difference between the B/S derived from the 2009 Lesotho DHS and the corresponding ratio derived from the 2006 Lesotho census after linking women to their biological children using the software MATCHTAB is 0.3%. The use of the direct mother-child link provided by the full birth history of the 2009 Lesotho DHS instead of linking mothers to their children in the Lesotho 2006 census using the matching software, MATCHTAB does not appear to introduce a significant difference in the ratio B/S. Thus, the left hand side of equation (2) is approximately the same for both the 2009 Lesotho DHS and the 2006 Lesotho census.

The MATCHTAB output provides the number of the surviving matched own-children aged *x* last birthday, $S(x)$, derived from the 2006 Lesotho census for the ages *x*=0, 1, 2, . . ., 14. To get comparable estimates with those from the 2009 LDHS, the study converts the distribution by age *x* last birthday of the surviving own-children derived from the 2006 census to an age distribution that is based on child ages *a* nearest birthday, $S(a)$, using the formula: $S(a) = 0.5*[S(x-1) + S(x)]$, where $x = a$ and *a*=2, 3, 4, . . ., 14. The research derives the distribution by age *a* nearest birthday of the surviving own-children, $S(a)$, from the 2006 census by assuming that mortality is uniform in the interval [*x*,*x*+1). With these values of $S(a)$, we estimate the proportionate age distribution of surviving own-children, $c_s(a)$, in a manner similar to the derivation of the corresponding estimates from the 2009 LDHS. Figure D1 shows that the proportionate age distribution of surviving own-children, derived from the 2006 Lesotho census after linking women and their biological children using the software,

MATCHTAB roughly coincides with the proportionate age distribution of surviving own-children derived from the 2009 Lesotho DHS for most of the child ages *a*=1, 2, 3, . . ., 14.

Figure D1 Proportionate age distribution of surviving children, $c_s(a)$



Given the similarity of the 2006 Lesotho census and 2009 LDHS estimates of B/S, $c_s(a)$, and consequently the $q(a)$ values, MATCHTAB provides a successful link of women to their biological children enumerated in the 2006 Lesotho census. The study utilises the direct mother-child link provided by the full birth history of the 2009 LDHS and the 2005-6 ZDHS instead of linking mothers to their children using the matching software, MATCHTAB because of the similarity of these estimates.

Appendix D3. Applying the fundamental equation of the own-child method to the data that are adjusted for the bias due to HIV

We derive the child mortality estimates that are corrected for the bias due to HIV using the following form of the fundamental equation of the own-child method:

$$\frac{B}{S^c} = \int_0^{\alpha} \frac{c_s^c(a)}{p^c(a)} da = \int_0^{\alpha} \frac{c_s^c}{l^c(a)} da \quad (3).$$

The calculation of the corrected estimates of child mortality using this form of the fundamental equation of the own-child method requires the same data that were used to derive the uncorrected estimates. However, the corrected number of surviving children aged *a* nearest birthday at the time of the survey, the $S^c(a)$ values are calculated using

the equation: $S^c(a) = B(t_s - a) * p^c(a)$, where $p^c(a)$, is the corrected cohort probability of surviving to age *a*, derived using the fitted curve of the HIV selection bias. We then compute the corrected number of those children ever-born to reporting women in the age range 15-34 that survive to the time of the interview, S^c, from the values of $S^c(a)$, akin to the manner in which the corresponding unadjusted estimate, *S*, was calculated. The left hand side of equation (3) is the ratio $\frac{B}{S^c}$ and the corrected proportions of surviving children who are aged *a* nearest birthday at the time of the survey can be estimated as: $c_s^c(a) = \frac{S^c(a)}{S^c}$.

Again, the set of the model $l^c(a)$ values that satisfy equation (3) is identified by trial and error. This is done by fitting a linear equation to the values of $\frac{c_s^c(a)}{l(a)}$ and the child ages, *a*, i.e. an equation of the form $\frac{c_s^c(a)}{l(a)} = \omega + \rho a$. The right hand side of equation (3) is then calculated as: $\int_0^{15} \frac{c_s^c(a)}{l(a)} da = \int_0^{15} (\omega + \rho a) da.$ For Lesotho, the model $l^c(a)$ values that provide the best fit to equation (3) lie between the levels 16 and 17 of the West family of the Princeton model life tables. We then calculate the level of mortality of the model that solves equation (3) by linear interpolation between the levels 16 and 17 using the value of $\frac{B}{S^c}$ that constitutes the left hand side of equation (3) and the values of $\int_0^{15} \frac{c_s^c(a)}{l(a)} da$ that are calculated from the model $l(a)$ values for level 16 and 17. The level of the model that solves equation (3) is 16.05. To obtain the values of $l^c(a)$ that best fit equation (3), we use linear interpolation between the tabulated values of $l(a)$ for the levels 16 and 17, using the levels 16, 16.05 and 17. The corresponding life table probabilities of dying by age *a* that are corrected for the bias due to HIV, the $q^c(a)$ values are calculated using the equation: $q^c(a) = 1 - l^c(a)$. The results for Zimbabwe reveal that the level of the model that solves equation (3) is 18.34.

Appendix D4. Applying the approach proposed by Preston and Palloni (1977) to the data that are unadjusted for the bias due to HIV

The estimation of childhood mortality using the approach proposed by Preston and Palloni (1977) requires the number of births *a* years before the survey that occur during the period $t_s - a - 0.5$ and $t_s - a + 0.5$, $B(t_s - a)$, and the distribution by age *a* nearest birthday of the surviving children, i.e. the $S(a)$ values for child ages *a*=1, 2, 3, . . ., 15, and for each age group of women *i* where *i*=1 refers to the 15-19 age group, 2 refers to the 20-24 age group, . . ., 4 to the 30-34 age group.

After extracting the data required to apply the approach proposed by Preston and Palloni (1977), we calculate, first, the number of children ever-born to reporting women in each age group *i*, $B(i)$, using the discrete relationship: $B(i) = \sum_{a=1}^{15} B(t_s - a).$ The number of children ever-born to reporting women in each age group *i*=1, 2, 3 and 4 that survive to the time of the interview, $S(i)$ is computed next as follows: $S(i) = \sum S(a)$. We then calculate the number of children dead reported by women in each age group *i*, $D(i)$, using the equation: $D(i) = B(i) - S(i)$ and the proportion of children dead for that age group by dividing the number of children dead by the number of children ever born to women in the age group.

The mean age nearest birthday of surviving children of reporting women in each age group *i*, $A_s(i)$, is estimated as: $A_s(i) = \frac{\sum_{a=1}^{15} aS(a)}{\sum_{a=1}^{15} S(a)}$ and the proportion of surviving children of reporting women in age group *i*, who are aged below 3 nearest birthday, $c_2(i)$ is computed as: $c_2(i) = \frac{\sum_{a=1}^{2} S(a)}{\sum_{a=1}^{15} S(a)}$.

For each age group *i* the multiplier, $k(i) = \alpha(i) + \beta(i).A_s(i) + \delta(i).c_2(i)$ is calculated using the regression coefficients $\alpha(i)$, $\beta(i)$ and $\delta(i)$ produced by Preston and Palloni (1977) that apply to the West family of the Princeton model life tables. The probability of dying by age *a*, $q(a)$ is estimated for each of the age groups of women as the product of the proportion of children dead for women in the age group and the multiplier for that age group. The $q(a)$ values are then converted to common indices of

mortality q_0 and ${}_5q_0$ using the West family of the Princeton model life tables as the standard tables in the Brass logit relational model with $\beta = 1$. The number of years before the survey $T_0(i)$, that these estimates of $q(a)$ apply is estimated by $T_0(i) = \alpha(i) + \beta(i).A_s(i)$, where $\alpha(i)$ and $\beta(i)$ are regression coefficients by Palloni (1980) for the West family of the Princeton model life tables and we use the values of $A_s(i)$ that were calculated earlier. The study approximates the survey date by the average of the survey start date and the survey completion date. We then assign a reference date to each $q(a)$ by subtracting the corresponding estimate of $T_0(i)$ from the approximate survey date.

Appendix D5. Applying the approach proposed by Preston and Palloni (1977) to the data that are adjusted for the bias due to HIV

Similar to the procedure used for women in the age range 15-34, the study fits separate quadratic curves of the HIV selection bias to the birth history data reported by women in the following age groups, 20-24, 25-29 and 30-34. The quadratic curves, fitted to the birth history data reported by women in these respective age groups in the 2009 Lesotho DHS are shown in Appendix C3, C4 and C5. For the age group 15-19, we can only estimate the values of the bias for the ages 1 and 2, $b(1)$ and $b(2)$ using the model by Blacker and Brass (2005) because there are few numbers of children ever born and children surviving in this age group. We calculate for each age group of women, *i* the corrected values of the cohort survival probabilities $p^c(a)$, using the estimates of bias derived for that age group.

The corrected distribution by age *a* nearest birthday of the surviving children of women in age group *i*, is then derived using the equation: $S^c(a) = B(t_s - a)\,p^c(a)$. The corrected number of children ever-born to reporting women in age group *i* that survive to the time of the interview, $S^c(i)$, is estimated as: $S^c(i) = \sum S^c(a)$ and the corrected number of children dead reported by women in the age group is given by: $D^c(i) = B(i) - S^c(i)$. For age group *i* the proportion of children dead that is adjusted for the bias due to HIV is given by the corrected number of children dead divided by the number of children ever born to women in the age group.

We derive, the corrected values of $A_s^c(i)$ and $C_2^c(i)$ by utilizing the same method used to derive the equivalent unadjusted values except that we now use the values of

$S^c(a)$ instead of $S(a)$. The estimates of the infant and the under-five mortality rate that are corrected for the bias due to HIV and their reference dates are then calculated in a manner similar to that used to derive the corresponding estimates for the uncorrected data. Conversion to common indices of mortality $q(1)$ and $q(5)$ is, however, done using as standard, a period life table derived using a SPECTRUM projection that incorporates HIV/AIDS and is derived as described in Appendix E.

Appendix E. Constructing a life table for Lesotho pertaining during the period 2004 from a SPECTRUM projection incorporating HIV/AIDS

Assuming there is no migration, we start by creating a SPECTRUM projection of the population and the annual number of births for Lesotho after incorporating the effects of the HIV/AIDS epidemic. The adjusted estimates of the infant and under-five mortality rate from the method by Preston and Palloni apply on average to the period 2004. Thus, we consider the projection output for the years 2004 and 2005 and the ages 0 to 5 years only.

We note though that the population projected for each year is the mid-year population while the projected births occur over a calendar year. Thus, if N_a^t is the mid-year population for year t aged a last birthday, then the survival probability of the population aged a to $a+1$ last birthday at time t over the period t to $t+1$ is estimated by: $S_a^t \approx \frac{N_{a+1}^{t+1}}{N_a^t} \approx \frac{L_{a+1}}{L_a}$.

Suppose B^t denotes the births that occur during the calendar year t, we calculate the births that occur between the middle of the calendar year t and the middle of the next calendar year $t+1$ by assuming that births are evenly distributed throughout a calendar year. Thus, half of the births in a year occur by the middle of the year. The births that are adjusted to be from the middle of a calendar year to the middle of the next year are calculated using the equation: $B_{adj}^t = 0.5 * (B^t + B^{t+1})$. This calculation is done for the year 2004.

The survival probability to time $t+1$ of births born in the period t to $t+1$ is estimated by: $S_B^t \approx \frac{N_0^{t+1}}{B_{adj}^t} \approx \frac{L_0}{l_0}$. With the radix set at 1, L_0 is calculated using the equation: $L_0 = l_0 * S_B^t$. The other values of L_a for a=1, 2, 3, . . .5, are calculated using the equation: $L_{a+1} = L_a * S_a^t$.

We then fit the curve of life table survivors, $l(a) = (1+\alpha a)^{-\beta}$ proposed by Blacker and Brass (2005) for the ages a=1, 2, 3, . . ., 5, using arbitrary values of α and β. From the relationship, $L_x = \int_x^{x+1} l(a)da,$ it follows that if the curve proposed by Blacker and Brass (2005) were to be used to represent the mathematical form by age of

the $l(a)$ values then, $L_x = \int_x^{x+1} (1+\alpha a)^{-\beta} da.$ This simplifies to: $L_x = \frac{(1+\alpha x+\alpha)^{1-\beta} - (1+\alpha x)^{1-\beta}}{\alpha(1-\beta)}$. We use this relationship to calculate the values of L_a for the ages *a*=1, 2, 3, . . ., 5. Finally, we solve for α and β values that minimize the sum of the squared difference of the values of L_a derived using the output data from the SPECTRUM projection and the corresponding values implied by the curve proposed by Blacker and Brass (2005). These values of α and β are used to produce a life table $l(a) = (1+\alpha a)^{-\beta}$ for the ages *a*=1, 2, 3, . . ., 5. A life table for Zimbabwe pertaining during the year 2000 is derived in a similar manner.

Appendix F. The number of children ever born and children surviving that are adjusted and unadjusted for the bias due to HIV/AIDS

Table F.1 Total births that occur *a* years before the date of the survey t_s, to women in age group *i*, Lesotho DHS 2009

	Years before t_s, (a)														
Age groups of women (*i*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15-19	117	54	24	4	1	3	2	1	0	0	0	0	0	0	0
20-24	305	266	199	182	129	80	39	16	7	4	0	0	0	0	0
25-29	183	203	174	229	211	169	214	175	129	115	62	45	13	8	4
30-34	122	120	124	139	122	146	177	169	162	196	194	168	149	130	74
Total	727	644	522	554	464	398	431	361	298	316	256	213	162	137	78

Table F.2 Total births that occur *a* years before the date of the survey t_s, to women in age group *i*, Zimbabwe DHS 2005-6

	Years before t_s, (a)														
Age groups of women (*i*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15-19	133	77	42	7	15	1	2	0	0	0	0	0	0	0	0
20-24	407	341	332	269	230	170	99	28	18	4	3	4	0	0	0
25-29	284	266	301	272	308	338	299	277	216	166	125	67	27	23	9
30-34	197	196	175	253	235	251	261	247	248	272	283	210	223	216	149
Total	1020	880	850	802	789	759	661	553	483	441	410	281	250	239	158

Table F.3 Surviving children aged *a* nearest birthday at the time of the survey t_s, by age group of the mother *i*, Lesotho DHS 2009

Age groups of women (*i*)	Child ages nearest birthday (*a*)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15-19	112	51	19	4	1	3	1	1	0	0	0	0	0	0	0
20-24	282	237	180	162	120	78	34	14	6	3	0	0	0	0	0
25-29	159	181	151	196	188	146	198	160	122	93	51	39	11	8	3
30-34	116	114	113	124	106	134	158	160	142	175	183	162	132	121	66
Total	670	584	463	486	416	362	391	334	270	270	235	201	143	128	70

Table F.4 Surviving children aged *a* nearest birthday at the time of the survey t_s, by age group of the mother *i*, Zimbabwe DHS 2005-6

Age groups of women (*i*)	Child ages nearest birthday (*a*)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15-19	125	62	37	7	13	1	2	0	0	0	0	0	0	0	0
20-24	383	318	306	250	210	158	95	27	15	4	2	2	0	0	0
25-29	259	251	285	244	286	315	285	271	204	151	119	63	25	16	9
30-34	188	184	163	239	217	230	251	230	235	258	264	201	213	194	128
Total	956	814	791	740	725	704	632	528	455	412	385	265	238	210	137

Table F.5 Corrected number of surviving children aged *a* nearest birthday at the time of the survey t_s, by age group of the mother *i*, Lesotho DHS 2009

Age groups of women (*i*)	Child ages nearest birthday (*a*)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15-19	105	48	0	0	0	0	0	0	0	0	0	0	0	0	0
20-24	274	236	170	161	119	68	31	14	0	0	0	0	0	0	0
25-29	169	176	147	197	176	151	189	162	104	98	59	0	0	0	0
30-34	115	106	107	115	107	123	157	140	137	177	180	146	137	117	66
Total	666	565	447	478	403	343	378	311	243	279	236	186	153	126	69

Table F.6 Corrected number of surviving children aged *a* nearest birthday at the time of the survey t_s, by age group of the mother *i*, Zimbabwe DHS 2005-6

Age groups of women (*i*)	Child ages nearest birthday (*a*)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15-19	125	72	38	0	0	0	0	0	0	0	0	0	0	0	0
20-24	382	317	304	248	206	155	92	26	15	0	0	0	0	0	0
25-29	261	250	281	238	278	304	274	261	197	146	116	61	25	16	0
30-34	188	182	160	232	210	222	242	222	228	251	259	198	213	196	131
Total	966	811	780	723	704	681	610	509	439	400	376	261	237	212	140

Appendix G. Estimates of infant and under-five mortality, Lesotho DHS 2009 and Zimbabwe 2005-6

Table G.1 Childhood mortality, fundamental equation of the own-child method, Lesotho DHS 2009

Age of child (a)	1	2	3	4	5
${}_aq_0$	72.6	86.4	92.8	97.2	100.7
${}_aq_0^c$	89.6	108.8	117.4	123.1	127.4

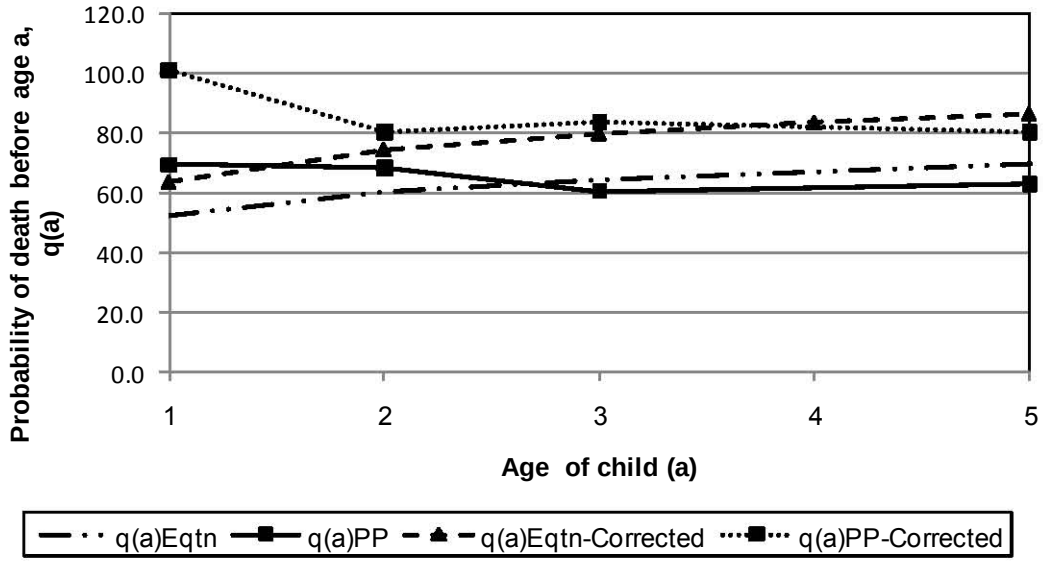
Table G.2 Childhood mortality, fundamental equation of the own-child method, Zimbabwe DHS 2005-6

Age of child (a)	1	2	3	4	5
${}_aq_0$	52.9	60.8	64.7	67.5	69.7
${}_aq_0^c$	63.6	74.6	80.0	83.6	86.6

Table G.3 Childhood mortality, Preston and Palloni approach, Zimbabwe DHS 2005-6

Age groups of women (*i*)	Age of child (*a*)	${}_aq_0$	Time	${}_aq_0^c$	Time
15-19	1	69.7	2002.6	101.2	2003.0
20-24	2	68.5	2001.2	80.6	2001.2
25-29	3	60.8	1998.7	83.9	1998.8
30-34	5	63.2	1996.5	80.5	1996.4

Figure G.1 Childhood mortality, fundamental equation and the Preston and Palloni approach, Zimbabwe DHS 2005-6



Appendix H. Estimates of the bias in the own-child method due to HIV/AIDS, Zimbabwe 2005-6

Figure H.1 Overall bias, selection bias, coefficient and timing bias, and the relative methodological bias, Zimbabwe DHS 2005-6

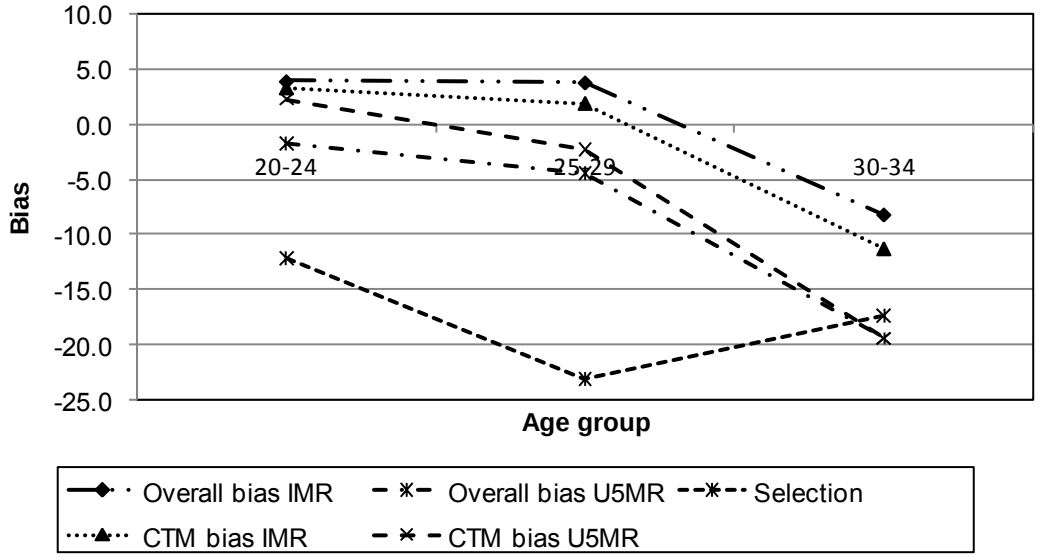


Figure H.2 Conversion bias due to the use of the Princeton model life tables, Zimbabwe DHS 2005-6

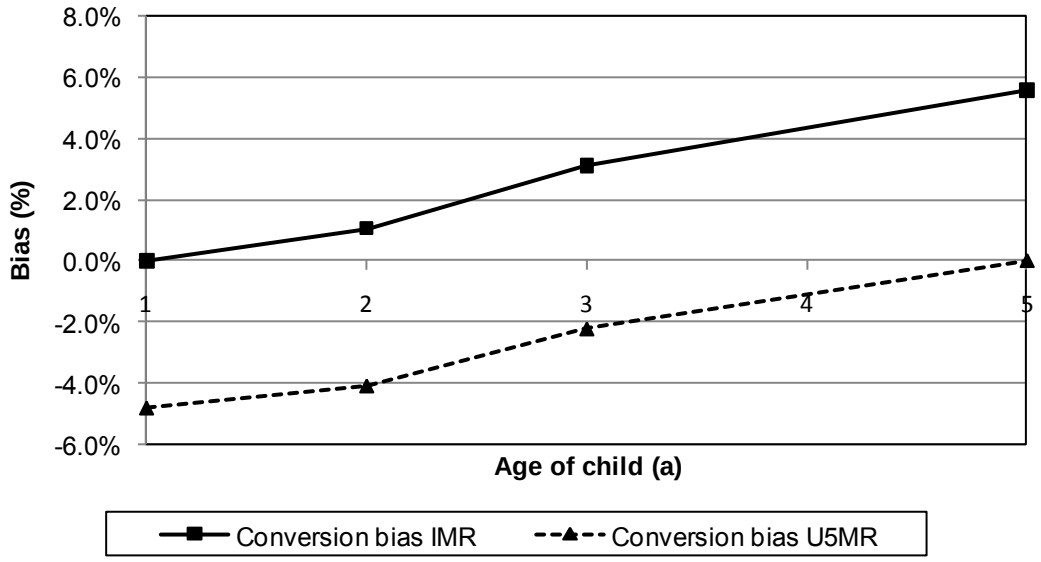


Figure H.3 Selection bias (%) Zimbabwe DHS 1988 and Zimbabwe DHS 2005-6

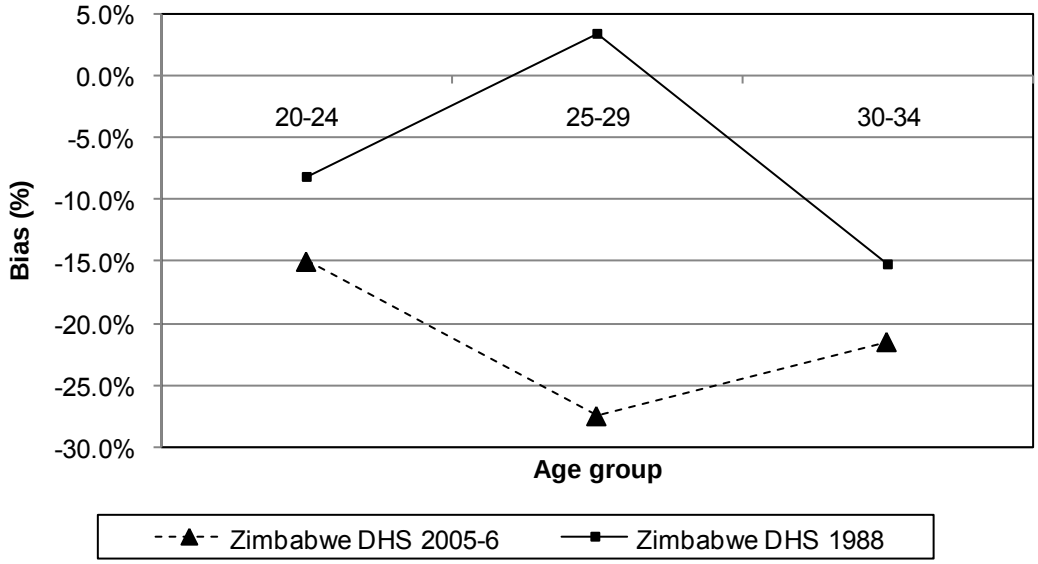


Figure H.4 Conversion bias due to the use of the Princeton model life tables, Zimbabwe DHS 1988