Assessment of the IGME methods of Estimating Infant mortality rate and Neonatal mortality rate from under-five mortality rate in Countries Affected by HIV/AIDS

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PLAGIARISM DECLARATION

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ABSTRACT

This study assesses the UN Inter-agency Group for Child Mortality Estimation (IGME) methods of estimating the infant and neonatal mortality rates from the under-five mortality rates in countries affected by HIV/AIDS. It uses Botswana, Malawi and South Africa as case studies.

The assessment is made by comparing the IGME results with estimates from projection models and empirical results computed from survey data and vital statistics data corrected for the level of incompleteness for the countries included in the study. In addition, relevant literature is reviewed in order to determine the reasonableness and impact (on the results produced) of the assumptions made by the method.

The IGME method for estimating the under-five mortality rate appears to produce estimates that are consistent with other empirical results for South Africa over the period of observation and for Botswana, except between 1998 and 2002 when it appears to produce exaggerated results for Botswana. The under-five mortality rates of Malawi are consistent with other results between 1980 and 1991, although the method appears to understate the results of Malawi during the period of high mortality of children due to HIV/AIDS, that is, after 1991. The IGME method of estimating the infant mortality rate from the under-five mortality rate appears to be affected by problems in the under-five mortality rate. For example, the infant mortality rate of Botswana between 1996 and 2003 are inflated and those of Malawi between 1992 and 1998 and after 2006 are underestimated, as are the under-five mortality rates in the corresponding periods. The method for estimating neonatal mortality produces results that exhibit an HIV trend and are exaggerated during the period of high mortality of children due to HIV/AIDS for countries having low background mortality (mortality due to all causes other than AIDS) and affected by HIV/AIDS, as shown in the case of Botswana and South Africa. The method appears to produce results that are consistent with empirical results determined by others for countries having high and rapidly falling background mortality despite being affected by HIV/AIDS, as shown in the case of Malawi.

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1 INTRODUCTION

1.1 Background

The level of mortality below the age of five years is an indicator of the level of development of a country in general and social development, such as health in particular. As a result, the reduction of under-five mortality has been set by the UN as one of the millennium development goals (MDGs). Thus countries design policies, implement programmes and allocate resources for reducing under-five mortality rate to achieve this goal.

Vital registration is the most important source of data for measuring the level and trend of under-five mortality rate (Ahmad, Lopez and Inoue 2000; Hill 1991; Setel, Macfarlane, Szreter *et al.* 2007), and hence for monitoring the progress towards the achievement of the millennium development goal, 4. Unfortunately, vital registration systems are non-existent or incomplete in developing countries, especially those in sub-Saharan Africa (Hill 1991; UNICEF, WHO, UNPD *et al.* 2011b). Therefore, countries in sub-Saharan Africa depend on data obtained from surveys for the measurement of under-five mortality (Mahy 2003; UNICEF, WHO, UNPD *et al.* 2011b). The level and trend of under-five mortality rates computed from different surveys vary due to differences in the method of computation, sources of the data and/or the quality of the data which cause difficulty in interpreting the trend in the under-five mortality (UNICEF, WHO, UNPD *et al.* 2007). Thus the UN Inter-agency Group for Child Mortality Estimation (IGME) fits a weighted regression model using the under-five mortality rates computed from data from different surveys and the times to which the estimates refer for estimating the level and pattern of the under-five mortality (UNICEF, WHO, UNPD *et al.* 2011a).

As under-five mortality declines due to efforts by countries to improve the health of their population and achieve the millennium development goal 4, the concentration of mortality in the infant and neonatal period becomes high (Obungu, Kizito and Bicego 1994). Moreover, the probability of dying in the first month of life and the first year are higher than any subsequent month or year (Lawn, Cousens and Zupan 2005; Sullivan, Rutstein and Bicego 1994). Therefore, the percentage contribution of infant and neonatal mortality to the under-five mortality increases over time. Hence countries which have designed policies and strategies for reducing under-five mortality need to know the level and causes of infant and neonatal mortality which contribute substantially to the under-five mortality (WHO 2006). For that reason, countries and international organisations have given nearly as much attention to the level and causes of infant mortality as to that of the under-five mortality.

As a result, the IGME has also developed a method for estimating the level and trend of infant mortality. For countries affected by HIV/AIDS the IGME estimates the infant mortality rate by interpolating the non-AIDS infant mortality from the non-AIDS under-five mortality rate using the Coale and Demeny or UN model life tables and then adding to this value, the HIV/AIDS infant mortality estimated by UNAIDS (UNICEF, WHO, UNPD *et al.* 2007, 2010). However, this method may not result in a reasonable level and pattern of infant mortality for African countries in general, and those affected by HIV/AIDS, in particular. This is because the AIDS cause under-five mortality (used for estimating the non-AIDS under-five mortality) and infant mortality estimated by the UNAIDS may not be necessarily correct. Further, the Coale and Demeny and UN model life tables are not based on the mortality experience of African countries. Moreover, the infant mortality rate is likely to be affected if any problem exists in the under-five mortality rate, since the infant mortality rate is determined from the under-five mortality rate.

Although the contribution of the neonatal mortality rate to the under-five mortality rate is also significant, less attention has been given for estimating it (Oestergaard, Inoue, Yoshida *et al.* 2011). As suggested by Martines, Paul, Bhutta *et al.* (2005) and Lawn, Cousens, Darmstadt *et al.* (2006), because little attention is paid to neonatal mortality, achieving the millennium development goal 4 could be less likely for most countries. As a result international organisations and countries have recently realised that increased attention should be given to neonatal mortality in order to reduce the under-five mortality and hence to achieve millennium development goal (MDG) 4. One of the mechanisms for increasing attention on neonatal mortality is the publication of estimates of neonatal mortality rates on an annual basis for each country (Lawn, Cousens, Darmstadt *et al.* 2006; Martines, Paul, Bhutta *et al.* 2005). Consequently improved methods of measuring neonatal mortality are emerging of which proposed by the IGME is one.

The IGME argues that since the quality of survey data on neonatal mortality is poor, and hence the neonatal mortality rate has to be estimated from under-five mortality, which is computed from data of relatively better quality. In the last few decades there has been a decline in under-five mortality rates in the developing countries, although this has stagnated and even reversed in some countries, particularly in sub-Saharan region due to HIV/AIDS. However, the decline in the neonatal mortality as compared to the under-five mortality is slow (Dinh, Nga, Malqvist *et al.* 2008; Hall 2005; Hill and Chio 2005; Hill and Pande 1997). Thus estimating neonatal mortality rate from the under-five mortality rate could produce incorrect estimates.

The results determined using the IGME models are widely used by countries and organisations which interpret the pattern and level of the under-five, infant and neonatal mortality rates and hence monitor the progress towards the achievement of the MDG 4. However, Alkema and Ann (2011) and Murray, Laakso, Shibuya *et al.* (2007) question the reasonableness of the IGME results, especially the under-five mortality rates and proposed a different approach.

This study determines the validity of the IGME methods and results by comparing them with other empirical estimates and assessing the consistency of the IGME results with the theory of the age pattern of mortality below the age of five years and assesses if the assumptions made by the method make sense for countries affected by HIV/AIDS.

1.2 Objective of the research

This section presents the general and specific objectives of the research.

1.2.1 General objective of the research

The purpose of this study is to assess the methods of estimating the infant and neonatal mortality rates employed by the IGME in high HIV prevalence countries using Botswana, Malawi and South Africa as case studies.

1.2.2 Specific objectives of the research

The specific objectives of the research are as follows:

1. To understand and describe how the IGME estimate the infant mortality and neonatal mortality from the under-five mortality.
2. To assess the reasonableness of neonatal and infant mortality rates computed from under-five mortality rate using the IGME method for the countries under study.
3. To draw conclusions about the relationship between the neonatal mortality rate and under-five mortality rate in an HIV/AIDS epidemic and hence about the methods employed by the IGME for producing the estimates.

1.3 Significance of the study

The IGME under-five, infant and neonatal mortality rates are widely used by countries and international organisations for determining the level and pattern of mortality below five years of age and hence help monitor and evaluate their policies and interventions in the area of health. However, Alkema and Ann (2011) and Murray, Laakso, Shibuya *et al.* (2007) question the reasonableness of the IGME under-five mortality rates. So far, no detailed study has been conducted validating the IGME methods of estimating the under-five, infant and neonatal mortality rates. This triggers, therefore, the need to conduct research that thoroughly assesses the reasonableness of the IGME methods and results, especially in countries affected by HIV/AIDS.

This study helps to determine whether the IGME methods and results are wrong or correct, and helps countries and organisations have some confidence in the assessment of the level and trend of mortality under the age of five years and enables them to plan accordingly. It may also assist the IGME to revise their methods.

1.4 Organisation of the dissertation

This study is organised into five chapters. Chapter 2 reviews relevant literature, namely: the IGME methods of estimating the under-five, infant and neonatal mortality rates; other approaches of estimating the infant and neonatal mortality rates from the under-five mortality rate; the age pattern of mortality below the age of five years; sources of data; and the method of estimating under-five, infant and neonatal mortality from survey and vital registration data. It also reviews the impact of HIV/AIDS on the methods for estimating infant and under-five mortality and the methods available for correcting the bias on these measures introduced due to HIV/AIDS, the impact of HIV/AIDS on neonatal survival and the trends in mortality measures under the age of five years. Chapter 3 presents the methods used to achieve the objectives of this research. It discusses the method of empirical and logical assessments of the IGME under-five, infant and neonatal mortality rates. The detailed assessment of the IGME methods and results are presented in Chapter 4. Chapter 5 concludes the dissertation with the discussion of the results, a presentation of the limitation of the research and scope for further research.

2 LITERATURE REVIEW

This chapter discusses the estimation of child mortality in general, and the estimation of infant mortality and neonatal mortality from under-five mortality by the IGME. Other approaches to estimating the neonatal and infant mortality from under-five mortality are also discussed. It also looks at sources of data, the methods of estimating under-five, infant and neonatal mortality from survey and vital registration data. Finally, it discusses the impact of HIV/AIDS on the estimation of under-five and infant mortality, methods for correcting the bias in the estimate of under-five mortality due to HIV/AIDS, the impact of HIV/AIDS on neonatal survival and trends of under-five, infant and neonatal mortality indicators in Botswana, Malawi and South Africa.

2.1 Estimation of under-five mortality by the IGME

Estimates of under-five and infant mortality rates given by different organisations within the UN system, such as UNICEF, WHO, UNPD and the World Bank, differed prior to 2004 because they were using different sources of data and methods of computation (UNICEF, WHO, UNPD *et al.* 2007). This created problems for appraising the achievement of MDG 4, and designing appropriate policies to ensure the achievement of this goal. As a result, the IGME, which consists of people from the UNICEF, WHO, UNPD, World Bank and a group of experts in the field (UNICEF, WHO, UNPD *et al.* 2011b) was formed in 2004. The purpose of forming this group, as indicated by UNICEF, WHO, UNPD *et al.* (2007), was to share data, to use standard methods, monitor progress towards the achievement of MDG 4, improve estimation methods and produce similar results and to allow comparison between countries.

The estimates of under-five mortality for most developing countries are obtained from survey data only, but in some developing countries they are obtained from both survey and vital registration data (UNICEF, WHO, UNPD *et al.* 2010). The levels and trend of under-five mortality computed from different data sources may differ widely, which causes difficulty in determining the likely pattern and level of under-five mortality in a given country. Therefore, the IGME estimates the average pattern and level of under-five mortality by fitting a regression curve to the estimates of under-five mortality computed from survey and vital registration data collected from 1960 onwards at their reference time points, however; for countries affected by HIV/AIDS the curve is fitted only to the non-AIDS under-five mortality. The type of the fitted curve is a weighted spline or loess regression curve depending on the level of the prevalence of HIV/AIDS in the country (UNICEF, WHO, UNPD *et al.* 2007, 2010).

According to the IGME, for countries with low levels of HIV/AIDS, that is an HIV prevalence rate of less than 5% at any point in time since 1980, a weighted linear spline regression[1] is fitted to the natural logarithm of the under-five mortality and the time to which the estimate refers. A linear spline regression allows the rate of change of under-five mortality to change over the entire period of observation (UNICEF, WHO, UNPD *et al.* 2010). Thus, the slope of under-five mortality, which changes at each knot, is assumed to be linear between knots. According to the IGME (UNICEF, WHO, UNPD *et al.* 2007), a set of under-five mortality estimates obtained from survey data using direct or indirect methods or estimates obtained from five years of vital registration data are assumed to represent a particular slope of under-five mortality (UNICEF, WHO, UNPD *et al.* 2010).

The weight assigned by the IGME to the estimates of under-five mortality depends on the source of the data, the accuracy of the estimates within that source of data (vital registration, full birth history or summary birth history data) and the estimation techniques used (direct or indirect) (UNICEF, WHO, UNPD *et al.* 2007). Moreover, the IGME assumes that the sum of the weights given to the under-five mortality rates computed from a full birth history data, summary birth history data and five years vital registration data is 5 and define a slope (UNICEF, WHO, UNPD *et al.* 2010). For each estimate computed from civil registration data a weight of 1 is assigned because the estimate is coming from a large data set and there is no significant difference between the time of death and the time of registration of the death. The weight given to an estimate computed from survey data is based on the time gap between the occurrence of the event and the reporting of that event. Accordingly, the estimates of under-five mortality referring to events further apart in time are less reliable than those referring to events in the recent period. Hence, the weight given to estimates derived from full birth history data differ according to the length of time before the survey date to which the given estimate of mortality refers. Thus, estimates in the five years immediately before the survey are given a weight of 2, estimates referring between

[1] The IGME (Hill, K., You, D., Inoue, M., Oestergaard, M.Z. *et al.* 2012, researchers working in the IGME) have changed the type of the regression model fitted to the under-five mortality rate of countries not affected by HIV/AIDS epidemic from spline to loess. One may question why this thesis could not take into account this change in the literature discussed above. However, by the time they released their work, the thesis has already been completed.

5 to 9 and 10 to 14 years before the survey date are given a weight of 1.8 and 1.2 respectively (UNICEF, WHO, UNPD *et al.* 2007).

The weight given to estimates computed using the Brass children ever born and children surviving method depends on the age of women in the reproductive age group. The estimates corresponding to women in the 15-19 and 20-24 age groups are given a weight of zero and 0.2 respectively, due to sampling problems and the higher mortality of children of younger women. Under-five mortality rates computed from data on women in the age group 25-29, 30-34 and 35-39 are assigned a weight of 1.2. The quality of data on children ever born/children surviving is assumed to be poor for older women, thus the weight given for an estimate computed using data obtained from women in the age group 40 to 44 is 0.8 and it is 0.4 for an estimate computed using data from women in the age group 45 to 49 (UNICEF, WHO, UNPD *et al.* 2007, 2010). If a given survey contributes two types of estimates using direct and indirect methods, the weights given to them are reduced to half in order to avoid over representing a particular data set. The sum of the weights is important for limiting the number and position of knots. A knot is determined by working backwards in time, beginning from the most recent estimate of under-five mortality. Thus whenever the sum of the weights of successive under-five mortality becomes a multiple of five a knot is determined; the only exception to this rule is the first knot. The first knot is determined in such a way that the sum of the weights for the remaining observation is at least five (UNICEF, WHO, UNPD *et al.* 2010).

The model that relates the natural logarithm of under-five mortality with the corresponding reference date is given as:

$$\ln(U5MR) = b_0 + b_1(date) + \sum_{i=1}^{n} b_i(date - k_i)_+ + \varepsilon$$

where *U5MR* is the under-five mortality rate, *date* is the calendar year or the reference date of the under-five mortality rate, n is the number of knots, $k_1, k_2, \ldots, k_n$, are the position of the knots, $(date - k_i)_+$ is equal to zero if date < k_i, and $(date - k_i)_+$ if date ≥ k_i, b_is represent the rates of change in the value of under-five mortality, ε is the error term which is assumed to be normally distributed around the natural logarithm of under-five mortality with a mean of zero and a constant variance.

The model fitted to the observed data is examined to decide if there are some inconsistent observations or outliers which are likely to affect the results. According to the IGME, if there are aberrant observations, the weights allocated to the aberrant data are reduced by a constant factor such as by multiplying the corresponding weights by 0.5, 0.25 or 0 and the model is fitted again with the revised weights (UNICEF, WHO, UNPD *et al.* 2007). This model is used to find a smooth trend of under-five mortality over the entire period and to project/estimate the value of under-five mortality for a required date.

For countries affected by HIV/AIDS (that is an HIV prevalence rate at any point in time since 1980 exceeding 5%, also HIV is firmly established in the general population and sexual networking in the general population is sufficient to sustain the epidemic) the under-five mortality rates are biased downwards because deaths of HIV-positive children are likely to be underreported since mothers of these children are also likely to die due to HIV/AIDS and hence their deaths are not reflected in the estimate. Thus a technique has been developed by the Technical Advisory Group (a group consisting of scholars in the field of Demography and Biostatistics) of IGME for correcting the bias in the under-five mortality rates computed from full birth history (see section 2.9.2 for further detail about the method used for correcting the bias). Since the IGME has not developed a method for correcting the bias in the indirect under-five mortality rates due to HIV/AIDS, the indirect estimates in the period of HIV/AIDS epidemic are excluded from the modelling process (UNICEF, WHO, UNPD *et al.* 2010). Moreover, the under-five mortality rates computed from full birth history data are also affected by birth transference (shifting births back in time). After correcting the bias due to HIV/AIDS and birth transference, the AIDS under-five mortality which is obtained by the UNAIDS is subtracted from the all-cause under-five mortality rate to get the corresponding non-AIDS mortality rate. A loess regression model is then fitted to the natural logarithm of the non-AIDS under-five mortality and the reference date. This model is then used to estimate/project the level as well as the pattern of the non-AIDS under-five mortality rates. The corresponding AIDS under-five mortality obtained from UNAIDS estimate is added back to the estimated/projected non-AIDS under-five mortality rate to get the overall under-five mortality rate (UNICEF, WHO, UNPD *et al.* 2010). According to the IGME, a loess regression model is fitted because it captures the dynamic nature of under-five mortality rates in these countries (UNICEF, WHO, UNPD *et al.* 2010). The loess regression model used by the IGME is given as:

$$y = \beta_0 + \beta_1 x + \beta_2 z + \varepsilon$$

where y is the natural logarithm of the non-AIDS under-five mortality, x is the time at which the rate applies, z is a variable which is 1 if the observed value is obtained from civil registration system and 0 otherwise and ε is the error term.

According to Silverwood and Cousens (2007), the loess regression equation is determined by using techniques of weighted least square regression. That is weights are allocated for all observed data, y using a weighting function in the following way. The weighting function is regulated by the value of □. Thus if the value of alpha is less than one the weighting function is calculated from the 100*□ % of the data. The weighting function is given as:

$$w = (1 - (\frac{\psi}{\Psi})^3)^3$$

where ψ is the minimum value of the absolute difference between *x-xo* (*xo* is the time point at which the estimate by the fitted model is required) and Ψ is the maximum value of the absolute difference between *x-xo* computed from 100*□ % of the data. But if the value of alpha is greater than one the weighting function involves all the data and it is given by the formula:

$$w = (1 - (\frac{\psi}{\Psi \alpha^{1/2}})^3)^3 .$$

Thus in order to fit a loess regression to the data for a given country, one starts with a minimum value of □ so that at least 3 points are used in computing the weight for a given y value, and then the fit of the curve is checked. If it is not good, the weights are recalculated with □ increased by 0.05 and the curve refitted and rechecked for goodness of fit. For alpha greater than one the value of alpha is increased by 0.1 at each step; but the maximum value of alpha should not be greater than two (Silverwood and Cousens 2007).

The IGME assumes a linear pattern of under-five mortality between knots. However, Alkema and Ann (2011) argue that this may lead to incorrect estimates of the level and pattern of under-five mortality, especially when there exist large variations among observations between knots. In addition, they argue that a linear spline causes sudden changes in the rate of change of under-five mortality between the knots, which results in instability in the estimated under-five mortality rates. Thus the above problem affects not only the value of the under-five mortality but also the infant and neonatal mortality rates which are computed from the under-five mortality rate. In addition Murray, Laakso, Shibuya *et al.* (2007) argue that it is difficult to reproduce the IGME results using the method described. They also argue that, in Sub-Saharan Africa the estimates of under-five mortality appear to be exaggerated, which could be because of the assumptions made about the likely impact of HIV/AIDS on child mortality, the absence of data for recent periods, the removal of certain estimates assuming that they are aberrant and the assumptions made about incomplete data. Hence, a spline regression used by the IGME for countries in sub-Saharan Africa except those affected by the HIV/AIDS epidemic (loess regression is fitted in these countries) does not address the above problems.

The IGME's technique for adjusting the bias in the under-five mortality estimates due to HIV/AIDS in the epidemic period only applies to full birth history data. Thus the estimates computed from summary birth history data in the period are excluded in the estimation process (UNICEF, WHO, UNPD *et al.* 2010). The exclusion of under-five mortality rates computed from summary birth history data in the modeling process is a loss of important information and probably the inclusion of these estimates in the modeling process would change the estimates released by the IGME.

2.2 Estimation of infant mortality by the IGME

The IGME produces a set of infant and under-five mortality estimates computed from survey data and/or civil registration data (UNICEF, WHO, UNPD *et al.* 2007). For countries with a reliable source of vital registration data a model is fitted to the relationship between the natural logarithm of the infant mortality rate and the reference date because vital statistics data provide a better estimate of the infant mortality rate than the under-five mortality rate (UNICEF, WHO, UNPD *et al.* 2007, 2010). However, for countries that rely on the full birth history data or summary birth history data, the infant death data may be poorer in quality than that used to estimate the under-five mortality rate. This is because the estimates of infant mortality rates computed from census data depend on the model life table used in the computation. Furthermore, in the case of full birth history data infant deaths are likely to be under-reported and may be wrongly reported as if they occurred in the age range between one and four years. However, all these problems are relatively less common for under-five death data than infant death data. Therefore in these countries the model is fitted to the under-five mortality rate rather than the infant mortality rate and the latter is determined from the under-five mortality rate estimated using the fitted model. The IGME uses different procedures for estimating the infant mortality rate for countries with high and low levels of HIV/AIDS. For countries with a low level of HIV/AIDS the infant mortality rate is interpolated from the under-five mortality rate using the Coale and Demeny model life table or UN model life table. However, in countries with a high level of HIV/AIDS, the non-AIDS under-five mortality rate is determined by subtracting the AIDS under-five mortality, which is obtained from the UNAIDS estimate. Then the non-AIDS infant mortality rate is interpolated from the non-AIDS under-five mortality rate using the Coale and Demeny model life table or UN model life table. The all-cause infant mortality rate is determined by adding the corresponding UNAIDS estimate of AIDS infant mortality rate to the resulting estimate of the non-AIDS infant mortality rate (Hill and Amozou 2006; UNICEF, WHO, UNPD *et al.* 2007).

2.3 Estimation of neonatal mortality by the IGME

The IGME has recently developed a method for estimating neonatal mortality from under-five mortality (WHO 2010). This estimates are determined by relating the observed neonatal mortality rates and under-five mortality rates computed from survey data and vital statistics data (Oestergaard, Inoue, Yoshida *et al.* 2011; UNICEF, WHO, UNPD *et al.* 2011a). These rates are adjusted to maintain consistency with the IGME's estimates of under-five mortality rates. In addition, the proportionate difference between the adjusted neonatal mortality rate and the under-five mortality rate computed from all mortality estimates is assumed to be the same. Two models have been developed by the IGME, depending on the source and quality of data available for measuring mortality rates (UNICEF, WHO, UNPD *et al.* 2010).

The first method is applicable for countries having high quality vital statistics data (with no incompleteness for adult data and where the discrepancy between the under-five mortality rates computed from vital statistics data and by the IGME is less than 15%), having very few missing neonatal and under-five mortality rates (for example if data between 1990 and 2009 are used for developing the model, there must be observations at least for 17 years out of the 20 years and the number of successive years with no observation are less than three). This method computes the ratios between the adjusted neonatal mortality rates and the under-five mortality rates. Thus if the neonatal mortality rate is unknown for a particular year of interest, it is estimated as the average value of the ratios closest to the year of interest multiplied by the under-five mortality rate in the corresponding year or if we want to project for short periods from one to two years the ratio of the most recent observations multiplied by the under-five mortality rate in the year of interest is used (Oestergaard, Inoue, Yoshida *et al.* 2011; UNICEF, WHO, UNPD *et al.* 2010).

The second method is used for countries which do not have high quality civil registration data. It fits a multilevel regression model to the natural logarithm of observed neonatal mortality and under-five mortality (without removing the HIV trend in the under-five mortality)[2] computed from the survey and vital registration data. This model was selected by the IGME as the best performing model among the available potential models after evaluating its prediction power by using the absolute and relative difference between the observed and predicted value of neonatal mortality rates. The inclusion of mortality estimates computed from data further back in time at each survey do not improve the prediction and estimation power of the model and also increases noise in the model, thus, it is fitted only to the recent data in a survey and only uses data from 1990 onwards (Oestergaard, Inoue, Yoshida *et al.* 2011; UNICEF, WHO, UNPD *et al.* 2010).

The equation of this model is:

$$\ln(NMR) = \alpha_0 + \beta_1 * \ln(U5MR/1000) + \beta_2 * \ln(U5MR/1000)^2 + \delta_{j[i]} + \theta_{k[i]} + \varepsilon_i$$

where $\delta_{j[i]}$ and $\theta_{k[i]}$ are country level and region level random effects respectively for observation *i*, *NMR* and *U5MR* are the neonatal and under-five mortality rates respectively, and ε_i is the error or random term and it is assumed to be normally distributed with mean zero.

2.4 Other approaches for estimating infant and neonatal mortality from the under-five mortality

2.4.1 The Blacker and Brass model and estimation of infant mortality rate

Blacker and Brass (2005) note that mortality declines at a faster rate during the early ages of life and then it levels off. Thus the pattern looks like a hyperbola. Blacker and Brass (2005) use this idea to model the life table survivorship curve at early ages of life with the following equation:

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

where x is the age in years or months; □ is a constant and measures the level of mortality (determine the rate of change in mortality) and □ is also a constant which measures the pattern of mortality. The value of alpha and beta need to be determined in order to get the value of the survival function at any age, either in months or years. If any two $l(x)$ values are known say $l(1)$ and $l(5)$ we can get the value of alpha and beta.

[2] During examination of the dissertation the IGME released revised estimates of neonatal mortality (Hill, You, Inoue *et al 2012*) which no longer make this mistake.

For illustration purposes Blacker and Brass (2005) used two data sets showing different patterns of mortality in the early ages of life. These are the 1992 Bangladesh data collected by the International Centre for Diarrhoeal Disease Research, which shows high mortality during infancy relative to mortality in the age range 1 to 5 and the other is the 1962-1968 data from Sine Saloum of Senegal, which shows a higher rate of mortality in the age band one to five as compared to infancy. They used the observed values of $l(6)$ and $l(60)$, where age is measure in months, from the Bangladesh data to find the value of alpha and beta. The estimates of $l(x)$ computed from the fitted model are very close to the observed values, except in the first month. Therefore, the discrepancy between the value of neonatal mortality determined by subtracting the estimated value of $l(1)$ from 1 and the observed neonatal mortality is relatively large. The model is also fitted to the data of Sine Saloum of Senegal using $l(6)$ and $l(60)$ and $l(12)$ and $l(60)$. The estimated values of $l(x)$ computed from the model fitted using $l(6)$ and $l(60)$ do not follow the observed pattern. However, the model fitted using the values of $l(12)$ and $l(60)$ produces results that follow the observed pattern as compared to the earlier model. Hence the model is not flexible enough to capture the different patterns of mortality and may not produce reasonable results for ages less than one year.

2.4.2 The Keyfitz model and estimation of infant mortality rate

Keyfitz (1966) suggests that the age pattern of morality at earlier ages doesn't follow an exponential or polynomial curve. He tried a few curves, for example, assuming a linear curve between l_0 and l_1 and a parabolic pattern between $l_{0,}$ and l_5. The curve which assumes a linear pattern of the survival curve during infancy produces a very high value of ${}_1L_0$ and the curve that assumes a parabola does not produce a result close to the observed value. Keyfitz (1966) proposes the following curve for the age pattern of survival at early ages:

$$l(x) = \frac{ax+b}{x+b}.$$

The values of a and b must be determined to compute the values of $l(x)$ at the early ages of life. Thus, if any two values of $l(x)$ say $l(x_1)$ and $l(5)$ are known, a and b are estimated simultaneously.

He checked the performance of the model by comparing the person year (${}_1L_X$) values produced by the model with observed values. He used the observed value of $l(1)$ and $l(5)$, where age is in years to determine the parameters of the model. The results produced by the model are almost the same as the empirical results up to the third digit.

The model may not produce reasonable probability estimates since the probability of dying and the person years lived are different measures which are computed differently.

2.4.3 The Weibull distribution and estimation of infant mortality rate

Carriere (1992) suggests that the age pattern of survival at the earlier ages can be modeled by a Weibull distribution as follows:

$$S(x) = \exp\left(-\left(\frac{x}{m} \right)^{\frac{m}{\sigma}} \right)$$

where m is a parameter that measures the mode of the distribution and σ is a parameter which measures the dispersion of the distribution. If two $l(x)$ values are given the value of m and σ are determined simultaneously from the above equation. This model is developed for modeling mortality at all ages by adding additional terms and not specifically for age pattern of survival at early ages like the Blacker and Brass and Keyfitz models, hence it is not used for assessing the IGME results.

2.4.4 The Heligman and Polard model

Heligman and Pollard (1980) propose that the age pattern of mortality at the early ages declines rapidly with an exponential pattern. Thus they suggest the following curve to model the age pattern of mortality at the early ages:

$$\frac{q_x}{p_x} = A^{(x+B)^c}$$

where q_x and p_x are the probability of dying and surviving between age x and x+1 respectively, A is a parameter that measures the level of mortality, B and C are also parameters that measure mortality change between age zero and one, and the rate of mortality decline, respectively. The model is a three parameters model and hence one cannot determine these parameters if only two $l(x)$s are given and it is include here for the sake of completeness and not used for assessing the IGME results.

2.4.5 The IHME method of estimating mortality measures under five years of age

2.4.5.1 The IHME method of estimating the under-five mortality rate

The Institute of Health Metric Evaluation (IHME) developed a technique for estimating/projecting the pattern and level of under-five mortality rates by fitting a model that relates the observed under-five mortality rates computed from different data sources to the time to which the estimates refer. Rajaratnam, Marcus, Flaxman *et al.* (2010) argue that using a single model to estimate/project the level and pattern of under-five mortality is wrong, because one cannot be certain that the fitted model is the best one. Moreover, this single model may not capture the change in the trend of under-five mortality over time and hence misses some patterns like the change in the pattern of the under-five mortality due to the HIV/AIDS epidemic. Therefore, in order to resolve the above issues the IHME fitted a loess regression model, $f(t)$ between the log of the under-five mortality rate and the time to which the estimates refer. Since there is uncertainty about $f(t)$, the IHME define a Gaussian process distribution over $X = f(t)$. The Gaussian process distribution assumes a normal probability distribution to any linear combination of $f(t)$ which is denoted as:

$$f \sim \mathrm{GP}(M, C),$$

where M and C denote the mean and covariance function.

The IHME include a term in the above model in order to take into account the level of incompleteness in the vital registration data. Thus the above model is modified as:

$$\mu_{t,s} = f(t) + \delta_{s=VRI} \cdot \beta_{VRI}$$

$$\beta_{VRI} \sim Normal(\mu_{VRI}, \delta^2{}_{VRI})$$

where $\mu_{t,s}$ is the logarithm of the under-five mortality at time t from a given data source, and s is the source of the data, $\delta_{s=VRI}$ =1 if the source of the data is incomplete vital and sample registration system and 0 otherwise, β_{VRI} is a term added to take into account the bias in the under-five mortality rates if the vital registration data is incomplete in a given country (see the web appendix of Rajaratnam, Marcus, Flaxman *et al.* (2010) for further detail about β_{VRI}).

The probability distribution of the above model is determined using the Bayesian approach to generate number of possible distributions. Hence Markov Chain Monte Carlo is used to sample 1,000 models after ignoring the first 3,000 models and the median value of the parameters and their 95% confidence interval are determined from the selected 1,000 models.

The major limitation of the IHME method is the use of the under-five mortality rates computed from survey data in the modelling process without making correction for the bias introduced due to HIV/AIDS.

2.4.5.2 The IHME method of estimating infant and neonatal mortality rate

The IHME estimated the sex-specific early neonatal, late neonatal, postneonatal, infant and childhood mortality rates from the under-five mortality rate in a two-step modeling process (Lozano, Wang, Foreman *et al.* 2011). In the first step they estimated the sex-specific under-five mortality rate. For this purpose, they used sex-specific under-five mortality rates computed from vital registration data and full birth history data. Those results computed from incomplete vital registration data, results coming from countries having a total number of under-five deaths below 200 and an unreasonable sex ratio at birth being excluded since they are unreliable. They grouped those data that are assumed as reliable into 20 bins and fit the following model:

$$\frac{{}_5q_{0\,male}}{{}_5q_{0\,female}} = \beta + \gamma_{{}_5q_0\,bin} + \gamma_{region} + \gamma_{country} + \varepsilon$$

where ${}_5q_{0\ \mathrm{male}}$ and ${}_5q_{0\ \mathrm{female}}$ are the male and female under-five mortality rates, respectively, β is a constant, $\gamma_{5qo\ bin}$ is the bin effect (an indicator that shows the group of the estimate), γ_{region} is the region effect, $\gamma_{country}$ is the country effect and ε is the random component. The bin effect ($\gamma_{{}_5q0\ bin}$) may not capture the non-linear relationship between the sex ratio at birth and the level of the U5MR, hence a loess regression is fitted between the bin effect (determined from the above model by substituting the value of the ratio of male to female under-five mortality rate, β and the country and the region effect), and the observed under-five mortality rate for both sexes, ${}_5q_0$, i.e. $\gamma'_{{}_5q0\ bin}=f({}_5q_0)$. Thus the above equation is modified as:

$$\frac{{}_5q_{0\,male}}{{}_5q_{0\,female}} = \beta + \gamma'_{{}_5q_0\,bin} + \gamma_{region} + \gamma_{country}\,.$$

Using the concept of sex ratio, the combined under-five mortality rate is expressed as:

$${}_5q_0 = \left(\frac{1}{1 + sex\,ratio\,at\,birth}\right) * {}_5q_{0\,female} + \left(\frac{sex\,ratio\,at\,birth}{1 + sex\,ratio\,at\,birth}\right) * {}_5q_{0\,male}$$

Thus the male and female under-five mortality rates are computed by solving the above two equations.

In the second stage a regression curve is fitted between each sex specific early neonatal, late neonatal, post neonatal, infant mortality and childhood, and the under-five mortality rate. The model is given as:

$$\log(pr(dying\ at\ age\ y)) = \beta + \gamma_{{}_5q_0\,bin} + \gamma_{region} + \gamma_{country} + \varepsilon\,.$$

Then a loess regression is fitted between the logarithm of the probability of dying at age *y* estimated using the above equation and the observed sex specific under-five mortality rate. The combined mortality rates including infant mortality rates are determined by combining the sex specific mortality rates. The neonatal mortality rate (NMR) can be determined from the postneonatal and infant mortality rate computed using the IHME model using the following formula:

$$NMR = 1 - \frac{1 - {}_1q_0}{1 - postneonatal\ mortality}.$$

2.5 Age pattern of mortality below five years of age

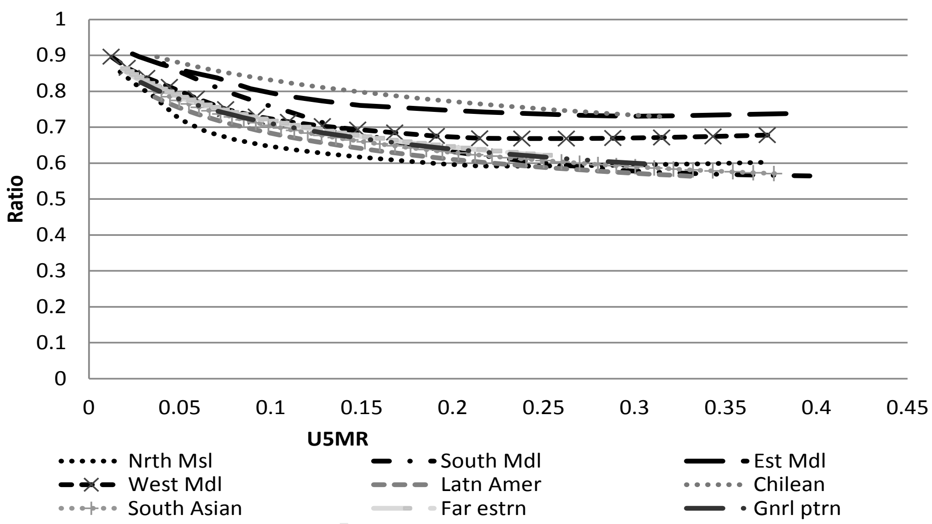
The probability of death differs markedly by age during the early years of life especially between ages 0 and 5 years (Obungu, Kizito and Bicego 1994; Sullivan, Rutstein and Bicego 1994), with the probability being highest during the first year of life (Sullivan, Rutstein and Bicego 1994). For example the percentage contribution of infant mortality to under-five mortality in Nigeria and Sir Lanka is about 74% and 93% respectively (Chaudhury, Gunasekera and Gunasekera 2006; Ojikutu 2008). The mortality rate also differs significantly at further age break-downs such as in months. The hazard of mortality in the first month of life after birth is higher than any one month age interval during the human life period (Lawn, Cousens and Zupan 2005). The neonatal mortality rate, therefore, contributes a considerable proportion, on average about 40% and 67%, to the world's under-five mortality and infant mortality rate, respectively (Hyder, Wali and McGuckin 2003; Lawn, Cousens and Zupan 2005). Lawn, Cousens and Zupan (2005) indicate that, the percentage contribution of neonatal mortality to under-five mortality differs from region to region and from country to country. Hall (2005) suggests that in regions such as Western Europe where the under-five mortality rate is very low, the percentage contribution of neonatal mortality to under-five mortality is estimated to be about 75%, whereas in sub-Saharan Africa where the under-five mortality is high the percentage contribution of neonatal mortality to under-five mortality is less than 25%. According to a report by WHO (2006), the share of neonatal mortality to under-five mortality is estimated to be 42% in Latin America. Another study conducted by Garde and Sabina (2010) using DHS data in South Asian countries having low level of child mortality, such as Bangladesh during 2007, Nepal in 2006 and Philippines during 2008, the contribution of neonatal mortality to under-five mortality is 48%, 53% and 45% respectively.

Obungu, Kizito and Bicego (1994) suggest that, as the rate of mortality between ages 0 and 5 years declines the proportion of the under-five mortality rate concentrated at the earlier age rises, especially during infancy and the neonatal period. Thus the ratio of neonatal mortality rate to under-five mortality rate and infant mortality rate to under-five mortality rate increases as the under-five mortality rate declines, also the ratio of the neonatal mortality rate to the infant mortality rate rises as the infant mortality rate declines (Hill and Pande 1997; Obungu, Kizito and Bicego 1994; Rao, Adair and Kinfu

2011). However, there is evidence that this increase in the ratio of the neonatal mortality rate to the under-five mortality rate following the reduction in the under-five mortality rate may be reversed when mortality rates are very low (Andreev 2011)

Figure 2.1 shows the plot of the ratio of infant mortality ($_1q_0$) to the under-five mortality ($_5q_0$) computed from the Coale and Demeny model life tables and the UN-model life tables for developing countries, showing that, as the under-five mortality declines, the ratio of infant mortality to under-five mortality increases.

Figure 2.1 Plot of the ratio IMR to U5MR against U5MR- from the Coale and Demeny and the UN model life tables



2.5.1 The common model life tables

2.5.1.1 The Coale and Demeny model life table

The Coale and Demeny model life tables are constructed using registered deaths by age obtained from populations living in developed countries (Pollard, Yusuf and Pollard 1991; Preston, Heuveline and Guillot 2001; UN 1983). The major limitation of the Coale and Demeny model life tables is that it is heavily weighted to the mortality experience of the European population and hence may not represent the mortality of populations in the developing countries. According to the pattern revealed, these life tables are grouped into four categories, such as: "West", "East", "North" and "South". The West pattern exhibits a mortality shape which is similar to the average mortality pattern revealed by all the available life tables; however, the remaining patterns (East, North and South) are significantly different from this pattern (Pollard, Yusuf and Pollard 1991). These model life table systems are discussed below.

The East pattern is characterised by high infant death rates as compared to the west pattern (UN 1983).

The North pattern shows a low level of mortality below age one coupled with a high level of mortality between ages one and five years (Preston, Heuveline and Guillot 2001; UN 1983).

The South pattern has high ratio of infant mortality to childhood mortality as compared to the West pattern when the under-five mortality is less than 125 per 1000 otherwise the pattern has low ratio of infant mortality to under-five as compared to the west pattern.

2.5.1.2 The UN model life table for developing countries

The UN model life tables are constructed using a collection of 72 life tables for each sex obtained from developing countries (UN 1983). The mortality patterns revealed by these life tables are categorised into the Latin American, the Chilean, the South Asian, and the Far Eastern patterns, depending on the geographical region predominant within each pattern group and the General pattern (the average pattern of all life tables) (UN 1982). The characteristics of these patterns are:

The Latin American pattern is characterised by a higher concentration of mortality during infancy than between ages one and five years as compared to the case in the General pattern.

The Chilean pattern shows very high mortality during infancy relative to the childhood period.

The Far Eastern pattern has some similarities to the Chilean pattern but has very low infant mortality as compared to the Chilean pattern.

The South Asian pattern has virtually the same ratio of infant mortality to childhood mortality as compared to the General pattern.

Although the UN model life tables for developing countries are constructed using data obtained from developing countries, the representativeness of the UN model life tables to the mortality of the population of Africa is questionable since the data included only one African country (UN 1983).

2.6 Sources of data for estimating neonatal, infant and under-five mortality

2.6.1 Vital registration

The registration of births and deaths on a continuous basis provides the most important and reliable information on the measurement of neonatal, infant and under-five mortality rates (Hill 1991). The vital statistics data are recorded shortly after the occurrence of the event of death or birth (UNICEF, WHO, UNPD *et al.* 2007), and thus provides timely information about the level of neonatal, infant and under-five mortality. However, in most developing countries, especially those in sub-Saharan that collect vital statistics data the quality of the data is poor (Ahmad, Lopez and Inoue 2000; UNICEF, WHO, UNPD *et al.* 2007). The births and deaths from poor and rural households are less likely to be reported and children from these households are more likely to die. Even in those countries which have a higher quality vital statistics data late registration of births and deaths is a problem. Mostly, those births and deaths not reported shortly after their occurrence are less likely to be reported later. Due to the above reasons, therefore, the estimates using vital registration may underestimate the true rate of mortality.

2.6.2 Sample registration

Sample registration systems record births and deaths prospectively from a representative of household. The system collects the required data on a regular basis (every six months or on a yearly basis) by following the same households (Hill 1991; Hill, Lopez, Shibuya *et al.* 2007). The data from this source are used to produce accurate estimates of mortality at ages below five years, especially the under-five mortality if the data collection process is carefully monitored (Hill 1991; UNICEF, WHO, UNPD *et al.* 2007). Sometimes the estimates from a sample registration system may not adequately represent the national figure since a very small portion of the population is covered by the system. For example in India, only 1% of the population are covered by the survey (Hill, Lopez, Shibuya *et al.* 2007). The system is implemented in only a few countries since it is very costly.

2.6.3 Census

Population censuses are another source of data for the measurement of infant and under-five mortality, but not neonatal mortality. Population censuses collect summary birth history data, survival of most recent births or births in the last 12 months and information about the previous birth. Most of the time it collects the required information from women in the age group 15 to 49 years about the number of children they have had and the number of children who are still alive (UNICEF, WHO, UNPD *et al.* 2007). Under-five and infant mortality rates are estimated from the summary birth history data (see section 2.7.1 for further detail).

In addition, a few censuses collect information about the survival of most recent birth or birth in the last 12 months. The proportion dead computed using data about the survival of births in the last 12 months is virtually the same as the IMR for a period of one year prior to the survey date. The proportion of dead computed using data about the survival of most recent births approximates the probability of dying at age two if the average birth interval is 2.5 years. The proportion underestimates the probability of dying at age two if the average birth interval is less than 2.5 years and overestimates if the average birth interval longer than 2.5 years (Hill and Aguirre 1990). However, the mortality estimates computed using data of the survival of births in the last 12 months or the most recent birth are under-estimated, probably due to under-reporting of births and deaths and/or due to few births occurring within the past 12 months (Hill 1991).

Blacker and Brass (2005) developed a method for estimating the infant mortality rate, *q*(1) from the proportion dead among children born in the last 24 months, *D* form survey data collected about the survival of previous birth. The method assumes that $l(x) = (1 + \alpha x)^{-\beta}$, where *x* is age in the early years of life after birth (see section 2.4.1 detail about the method). Thus *D* is estimated as: $1 - \frac{1}{2}\int_{0}^{2} l(x)dx$, and $q_{(1)} = 1 - (1 + \alpha)^{-\beta}$

An adjustment factor *q*(1)/D, which is used for converting the proportion dead among births in the last 24 months into *q*(1) can be determined if alpha and beta are known. They determined the correction factor using simulation approach, and the correction factor ranged from 1.04 to 1.097 with an average value of 1.092. Mostly the proportion, *D* is multiplied by 1.092 since the estimate is robust to the selection of correction factors Blacker and Brass (2005) .

2.6.4 Household surveys

Censuses are generally conducted once every 10 years and the vital statistics registration system is incomplete or non-existent in most developing countries. Therefore it may be difficult to get estimates of neonatal, infant and under-five mortality rates over inter-censual periods. A possible option is to include information on child mortality in surveys (Hill 1991). Demographic and health surveys (DHSs) and the multiple indicator cluster surveys (MICSs) are the most common ones used for the measurement of mortality between ages 0 and 5 years (Mahy 2003). Demographic and health surveys collect full birth history data from women in the child-bearing age group. Thus DHSs ask women about the month and year of birth for each live-birth. If the child has died, the DHS collects the age at death in days, if the death occurred within the first 28 days after birth, in months, if the death occurred between one and 23 months, and in years if death occurred between ages two and five (Hill and Chio 2005). This information is used for computing neonatal, infant and under-five mortality rates.

Multiple indicator cluster surveys were initiated by UNICEF in countries which have conducted very few surveys or have not conducted a recent DHS, in order to help these countries appraise the progress towards the achievement of millennium development goals (Mahy 2003; UNICEF, WHO, UNPD *et al.* 2007). This survey collects summary birth history data from women in the reproductive age group, which is what censuses do.

The most common problem with DHS data is heaping of age at death to whole numbers. Thus deaths occurring at days close to one month, 12 or 18 months may be reported as if they occurred on one month, 12 and 18 months after birth respectively. Moreover, since the survey asks women about the occurrence of events that occurred in the distant past, women may not be able to remember all of the events (births and deaths) and dates of occurrence of these events. The data obtained from surveys are affected by the selection method, death of the mother and migration. The data are also severely affected in countries affected by HIV/AIDS (Hill 1991).

2.7 Methods of estimating mortality under the age of five

2.7.1 Indirect method of estimating infant and child mortality

Brass developed a method that converts the proportion of children dead among children ever born to women in the reproductive age group into probabilities of dying before reaching specific ages (Brass, Coale, Demeny *et al.* 1968; Mahy 2003; UN 1983). Thus if D_i represents the proportion of children dead as reported by women in age group i (i = 1 if the age group is 15 - 19, 2 if the group 20 - 24 and so on) then the probability of dying before age x is given:

$$q_{(x)} = (D_i)(k_i)$$

where k_i is the multiplier or factor for converting the proportion dead of children born to women in the i^{th} age group into the probability of dying. Brass also determined that the most accurate probability measures computed using summary birth history data obtained from women in the age groups 15 - 19, 20 - 24,…,45 - 49 are the probability of dying before age 1, 2, 3, 5, 10,15, 20, respectively (Brass, Coale, Demeny *et al.* 1968).

Brass pointed out that the association between D_i and the probability of dying is determined by the age distribution of fertility. Thus k_i is a function of the age pattern of fertility and mortality, and it is estimated by:

$$k(i) = a(i) + b(i)\frac{p_1}{p_2} + c(i)\frac{p_2}{p_3}$$

where $k(i)$ is a multiplier, $a(i)$, $b(i)$ and $c(i)$ are coefficients specific to each of the Coale and Demeny model life tables patterns and p_1, p_2, and p_3 are average parties of women in the age group 15-19, 20-24 and 25-29, respectively.

The probabilities of death computed from summary birth history data using the Brass method refer to periods in the past. Thus if mortality changes over time at a constant rate, then the time to which the estimate refers is given by:

$$t(i) = a(i) + b(i)\frac{p_1}{p_2} + c(i)\frac{p_2}{p_3}$$

where $t(i)$ is the time to which the estimate refers, $a(i)$, $b(i)$ and $c(i)$ are coefficients calculated for each of the Coale and Demeny model life table patterns, determined using analysis of simulated regression models (Hill 1991; UN 1983).

The probability of dying estimated using the Brass method is based on a number of assumptions, the most important being that the survival of a child is not affected by the death and age of the mother, birth order and other factors and is only affected by the age of a child. However, these assumptions may not be always true; for example, children of women in the age group 15-19 have a higher risk of dying than their counterparts (Hill 1991; Mahy 2003; UN 1983) and hence the child mortality rates for recent periods may be inflated.

The other assumption made in this method is that fertility and mortality rates are assumed to be constant in the recent past. However, these rates are declining in most countries, although mortality has reversed due to HIV/AIDS in countries affected by the epidemic. Thus an assumption of constant fertility biases the mortality estimates upward. The assumption of constant mortality in the original Brass method is relaxed by Coale and Trussell (1974) and Feeney (1980). The other assumptions made by the method are affected by HIV/AIDS (see section 2.8 for details about the impact of HIV/AIDS on the assumptions).

Common mortality measures, such as infant and under-five mortality rates, are computed from $q_{(x)}$ values determined by using the Brass method in order to see the trend of under-five or infant mortality (UN 1990). Brass related linearly the logit transformation of the curve of probability of dying of two life tables having the same pattern (UN 1983; Zaba 1979), i.e.

$$\operatorname{logit}(q_{(x)}) = \alpha + \beta * \operatorname{logit}(q_{(x)}{}^{s})$$

where $\log it(q_{(x)}) = \frac{1}{2}\ln\left(\frac{q_{(x)}}{1-q_{(x)}}\right)$, $q_{(x)}$ and $q^{s}_{(x)}$ are the probability of dying by age x produced using the Brass method and obtained from a standard model life table, respectively, α and β are parameters which measure the level and pattern of mortality respectively. If the pattern of the observed $q_{(x)}$s is the same as the standard model life table then β = 1. Therefore, from the above equation α is given as

$$\alpha = \log it(q_{(x)}) - \log it(q^{s}{}_{(x)}) \; .$$

Thus once the value of α implied by the value of each $q_{(x)}$ is determined the common measures are computed using the following equation:

$$_{x}q_{0} = 1 - (1 + \exp(2(\alpha + \log it(q^{s}{}_{(x)})))^{-1}.$$

2.7.2 The direct method of estimating mortalities under the age of five years

The direct method of estimating mortality uses information of the date of a child's birth, survival status of a child and age at death (in days, months or years) if the child died, collected from women in the reproductive age group (Rutstein and Rojas 2006). The mortality rates are determined from the data using the following approaches. *The synthetic cohort approach* divides the first five years after birth into intervals of below 1 month, 1-2, 3-5, 6-11, 12-23, 24-35, 35-47, 48-59 months and computes the probability of dying in each interval by dividing the number of deaths in the interval by the number of surviving children at the beginning of the interval in a specified time period. These probabilities are then combined to get common measures of the probability of dying. For example, infant mortality is determined by subtracting from one the product of the complement of the probability of dying (i.e. probability of surviving) in the intervals below one month, 1-2, 3-5 and 6-11 (Rutstein and Rojas 2006). *The vital statistics approach* uses information of the number of births and infant deaths in the period (year) of interest in order to determine the infant mortality rate. Thus this rate is determined by dividing the number of infant deaths by the number of births in the period of interest. The under-five mortality rate is determined using the following equation:

$$_{5}q_{0} = 1 - \exp\left(-\sum_{x=0}^{4} {}_{1}m_{x}\right)$$

where $_{1}m_{x}$ is the mortality rate between ages x and x+1 and x = 1, 2, 3 and 4. The mortality rate is determined by dividing the number of deaths between ages x and x+1 by the mid-year population aged x in the corresponding period. However, this method is limited to countries that have a complete vital statistics registration system (UN 1992). *The true cohort life table approach* uses information of the number of deaths in the cohort between two periods and the size of the cohort at the beginning of the period. Thus the cohort neonatal mortality rate is determined by dividing the number of deaths of children under age one month of a specified cohort by the number of births in that cohort. Similarly, the cohort infant mortality and cohort under-five mortality rate is determined by dividing the number of deaths below 1 year and 5 years by dividing the number of births in that cohort (Rutstein and Rojas 2006).

2.8 Impact of HIV/AIDS on the estimation of infant and child mortality

Most developing countries, especially those in sub-Saharan Africa, depend on census or survey data obtained from women of reproductive ages, for the estimation of infant and under-five mortality (Hill 1991; UNICEF, WHO, UNPD *et al.* 2007). Children of mothers infected with HIV have a higher chance of dying due to vertical transmission of HIV to the child or due to the indirect impact of HIV (Hallett, Gregson, Kurwa *et al.* 2010; Marston, Zaba, Salomon *et al.* 2005; Nakiyingi, Bracher, Whitworth *et al.* 2003; UNICEF, WHO, UNPD *et al.* 2007). In countries affected by HIV/AIDS deaths of these children are under-reported in surveys or censuses due to the death of HIV-positive mothers (Zaba, Marston and Floyd 2003). Thus the estimates of infant and under-five mortality rates computed from survey and census data using the direct and indirect method tend to underestimate the true rates.

The impact of HIV/AIDS is higher on the indirect estimates than the direct estimates. This is because many of the assumptions of the indirect method are violated in contrast to only one for the direct method, as discussed below.

The indirect estimation method of child mortality assumes that there is no association between child survival and age of mothers. However, the prevalence of HIV/AIDS varies with the age of a woman. Thus children born to women in the high HIV/AIDS infected age group are more likely to be infected with HIV and hence have a higher chance of dying. Therefore the survival status of children is dependent on the age of the mothers (Mahy 2003). According to a study by Stover, Johnson, Hallett *et al.* (2010) the incidence of HIV is high among women aged between 20 and 25 years. Assuming that the average survival of infected women is 10-15 years and give birth with in four years since infection the indirect estimate computed using data obtained from women aged 30-34 are under-estimated (Stover, Johnson, Hallett *et al.* 2010; UNICEF, WHO, UNPD *et al.* 2010).

The Coale and Demeny model life tables are used for converting the proportion dead into probability of dying. In addition, these probabilities ($q_{(x)}$) determined using the

Brass method are converted into common measures, such as infant (${}_1q_0$) and under-five (${}_5q_0$) mortality rates using the Coale and Demeny model life tables. Moreover, the coefficients used for estimating the time to which the infant and under-five mortality rates refer are determined from the Coale and Demeny model life table. However, these model life tables are constructed based on mortality data from HIV free populations, and do not show the mortality pattern of populations affected by HIV/AIDS. The mortality estimates using these model life tables, therefore, are biased downwards (Mahy 2003), and the time location of the under-five and infant mortality estimates for populations with HIV/AIDS may be incorrect. However, studies by Chitiyo (2011) and Mutemaringa (2011) suggest that the biases in the mortality measures as well as the time to which the estimates refer as a result of using the Coale and Demeny model life tables are insignificant.

The direct and indirect estimation methods of child mortality use full birth history data and summary birth history data respectively, collected from women in the childbearing age group. The direct and the indirect methods of child mortality assume that the survival status of children is independent of the death of the mother. However, in countries affected by HIV/AIDS this assumption is violated because of the significant association between the survival status of a child and death of a mother (Adetunji 2000; Nakiyingi, Bracher, Whitworth *et al.* 2003) and surveys cannot collect information about the survival status of children from HIV positive mothers due to the absence of a mother due to her HIV/AIDS death. Thus the estimates of infant and under-five mortality may be biased downward. However, these mortality estimates computed from full birth history data that occurred in the last five years are affected to a lesser extent compared to those data covering the earlier period because HIV positive women who give birth in the last 5 years are less likely to have died (Mahy 2003).

2.9 Methods of correcting the bias due to HIV/AIDS on child and infant mortality estimation

2.9.1 The Ward and Zaba correction method

Ward and Zaba (2008) estimated the bias due to HIV/AIDS in the estimates of child mortality computed using the Brass CEB/CS method by simulating a stable population with different stable levels of HIV prevalence among women aged 15-49 years. A cohort of HIV negative women aged 15-49 years which reduces in size due to HIV infection and non-AIDS mortality is projected with time. For each simulation of HIV/AIDS prevalence, the true value of child mortality $q(z)^t$ is computed. They estimated also the child mortality rate, $q(z)^e$ using the indirect method based on data that would have been reported by women if a cross-sectional survey was conducted. The difference between these two estimates approximates the error, $n(z)$, introduced by HIV/AIDS in the indirect techniques of child mortality estimation.

Ward and Zaba fitted a regression equation between the prevalence of HIV among women in the childbearing age group and the $n(z)$ values to estimate correction factors in the estimates of child mortality determined from birth history data. The regression equation is given as follows:

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

where *a, b* and *c* are regression coefficients for each five years reproductive age group and *PREV* and *PREV15* are the prevalence of HIV among women in the age group 15-49 and 15-19 respectively. Then the corrected estimate of child mortality is given as:

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

This method assumes that the population for which the estimates are required is stable and the prevalence of HIV is constant in the population. These assumptions are not true in practice. In addition, the method also assumes that the vertical transmission of HIV and mean survival time of adults is constant over time. These assumptions also do not hold true because the vertical transmission of HIV is reduced due to PMTCT programmes and the introduction of ART drugs (Dube, Boily, Mugurungi *et al.* 2008; Mahy 2003; Palombi, Marazzi, Voetberg *et al.* 2007; Stover, Fidzani, Molomo *et al.* 2008).

2.9.2 The IGME (Hill and Walker) correction method

The IGME has developed a method for correcting the bias introduced by HIV in full birth history data. The size of the bias depends on the extent to which child deaths are under-reported in surveys due to deaths of women because of HIV.

The latest information about the prevalence of HIV/AIDS among pregnant women in the age group 15-49 years and the annual number of births obtained from UNAIDS for the population under study are used by the IGME to get the true births and under-five deaths for each year. These births are divided into three categories: HIV-negative births from HIV-negative mothers; HIV-positive births from HIV-positive mothers and HIV-negative births from HIV-positive mothers. The model assumes that 35% of the births from HIV-positive mothers are HIV-positive (a transmission rate when the impact of PMTCT is ignored)[3]. For each annual number of births, deaths of children below five years are calculated for each category of births (HIV+ and HIV- births). The mortality experience of HIV-negative births is assumed to be the same regardless of the HIV status of the mother. Thus the under-five mortality rate of HIV-negative births is determined using the "West" family of the Coale and Demeny model life tables. The mortality schedule for HIV-positive births is determined from cohort studies with an under-five mortality rate of 0.625. Moreover, it is also assumed that the impact of ARV is negligible before the year 2007.

The IGME also determined the number of births and under-five deaths that would be reported by women in populations affected by HIV if a survey was conducted. In doing so, the IGME assumes that all HIV-negative women survive to the date of the survey, and hence births and deaths of all the children of these women are reported. In addition, the IGME assumes that an HIV-positive woman gives birth on average four years after infection. A survival curve with median survival time of 9.5 years since infection, obtained from cohort studies is used to create a mortality schedule of women after four years since infection. This curve helps to find the probability of survival of women from a given year to the survey date, which helps to find the number of births and under-five deaths reported by HIV-positive woman at the time of the surveys.

The estimated bias due to HIV in full birth history data is determined as the ratio of the reported number of deaths of children divided by the reported number of children below five years of age to the true number of deaths of children divided by the true number of children below five years of age for each estimate corresponding to the periods 0-4, 5-9 and 10-14 years prior to the survey date. The under-five mortality rates computed from full birth history data can then be divided by this ratio in order to get the correct estimates of under-five mortality rates.

The reasonableness of some of the assumptions made in this method such as: same survival status of HIV-negative births irrespective of the HIV status of the mother, births infected with HIV before and during delivery and through breastfeeding have same survival status, a median survival time of 9.5 years since infection, 35% of the births of HIV-positive mothers are HIV-positive and ART does not have an impact on the survival of children before 2007 are suspect and the impact of these assumptions on the resulting estimates are discussed in the result section (see section 4.1.3 for further

[3] Walker, Hill and Zhao (2012), revised the IGME method that corrects the bias in child mortality computed form full birth history data by taking into account the impact of PMTCT on the reduction of the chance of HIV transmission from mother to child. Unfortunately this was only published while this dissertation was under examination.

detail) since this study aims to assess the IGME results also by assessing the impact of these assumptions on the estimates.

2.9.3 The Hallet, Gregson, Kurwa *et al* correction method

Hallett, Gregson, Kurwa *et al.* (2010) use annual female birth cohorts in rural Zimbabwe between 1920 and 2005 obtained from the United Nations Population Division in order to develop a stochastic simulation model. The model simulates the mortality and fertility patterns at individual level for each female birth cohort. In addition, the method produces information about the survival of the children of birth cohorts of women between 1920 and 2005.

In order to get the non-AIDS mortality data, exponential models are fitted to the non-AIDS mortality pattern of the birth cohort for ages below 1 year and between 1 and 4 years separately, using observed mortality rates before the period of HIV/AIDS. For ages 5 years and above, the non-AIDS expectation of life is determined using the non-AIDS mortality data obtained from the Manicaland, Zimbabwe HIV/STD prevention study.

The non-HIV age-specific fertility rates for the rural birth cohorts are determined based on the observed rates before the start of HIV/AIDS epidemic. The HIV/AIDS age specific fertility rates and the rate of new HIV infection by age for the rural birth cohorts are determined using the observed rates from the Manicaland HIV/STD prevention study. A Weibull survival curve fitted to data from cohort studies in a number of African countries is used to determine the survival status of HIV positive women.

The model assumes that the woman starts taking ART when her CD4 count is less than 200 per microlitre of peripheral blood and the median time to death after the initiation of ARV is assumed to be 10 years. Moreover, ART is assumed to reduce the risk of HIV transmission to the child by 50%. The model also takes into account the dependence of the rate of HIV transmission from mother to child on the stage of the disease. The other assumption made by the model is that the survival time of an HIV-positive child is calculated as the minimum of the life expectancies in the absence of AIDS.

The model generates three types of data sets similar to those collected by DHS surveys. Accordingly, three types of infant and under-five mortality rates are computed from the data generated by the model over the period of observation. The first is the "DHS analogue", when these series of infant and under-five mortality rates are computed using the same method used in determining the infant and under-five mortality in DHS surveys. The second series is the "DHS continuous", when the estimates are computed on a continuous basis, assuming that the data are obtained from a very large number of closely-spaced surveys and no censoring of child survival times. The third one is the "corrected" series, determined in the same way as the DHS continuous but in this case simulated child mortality data of women who died due to AIDS are included in the computation. The bias introduced due to HIV in the estimates of infant and under-five mortality is estimated by the difference between the corrected series and the DHS continuous series.

This model also does not allow for the existence of variation between the survival of HIV-negative children born from HIV-positive and HIV-negative mothers (see section 4.1.3 for details about the impact of the failure to include this fact on the results estimates).

2.10 The impact of HIV/AIDS on neonatal survival

This section discusses the impact of HIV/AIDS on the survival of children of HIV-positive mothers in the neonatal period. Brocklehurst and French (1998) used meta-analysis and a systematic review of literature related to the impact of HIV/AIDS on neonatal mortality conducted between 1983 and 1996. In order to reduce methodological biases they included only research based on prospective cohort studies with sufficient data to compute confidence interval for the odds ratio. They found 31 studies which satisfy the above requirements. According to their study, adverse pregnancy outcome is significantly correlated with the HIV-status of women and hence there is an excess risk of perinatal and infant mortality of children from HIV-positive mothers. However, although the odds ratio of neonatal mortality of children born to HIV-positive mothers was 1.1, it was insignificant at the 5% level of significance. They thus suggested that the correlation between HIV status and adverse pregnancy outcome could be because of confounding factors.

A retrospective study conducted among 896 pregnant women (8.2% of whom were HIV-positive) admitted to St. Albert's Mission Hospital, Zimbabwe suggests that perinatal mortality and infant mortality in the neonatal period was high. The situation is exacerbated for the women co-infected with HIV/AIDS and Malaria (Ticconi, Mapfumo, Dorrucci *et al.* 2003). Another prospective study conducted by Villamor, Msamanga, Aboud *et al.* (2005) in Tanzania on 275 HIV positive women indicates that there is a significantly greater neonatal mortality risk of children of HIV-positive women co-infected with malaria than children of their counterparts. This is because HIV/AIDS increases the transmission rate of the malaria parasite to the child during pregnancy. A follow-up study conducted in Lusaka, Zambia on 1,229 HIV-positive pregnant women indicates that viral load is associated with maternal low body mass index, prematurity and low birth weight which are strong risk factors for neonatal mortality. However, the study concludes that deaths of infants due to HIV in the neonatal period is significantly small (Kim, Mwiya, Kankasa *et al.* 2011).

A follow-up study conducted in Malawi on 2,608 women, 5.8% of whom were HIV positive, suggests there is no significant risk of neonatal mortality among children of HIV-positive mothers as compared to children of their counterparts (Bloland, Wirima, Steketee *et al.* 1995). A retrospective study conducted at Mowbray Maternity Hospital (MMH), South Africa on 18,870 births, 17.2% of them were to HIV-positive mothers, concludes that the odds of the early neonatal death rate among births from HIV-positive mothers is not significantly different from births from HIV-negative mothers. The possible explanation for this may be due to the high quality of neonatal care at MMH (Kennedy and Fawcus 2012). A prospective study conducted on 2,850 women (50.8% of whom were HIV-positive) attending antenatal clinics in Kwazulu-Natal, South Africa reveals that children of HIV-positive mothers do not show a significant risk of death as compared to children from HIV-negative mothers in the first six weeks of life (Rollins, Coovadia, Bland *et al.* 2007). A further study conducted in South Africa, which analysed registered infant deaths between 1997 and 2002 with age in month, found a significant rise in mortality between ages two and three months after birth, which could be attributed to HIV/AIDS, suggesting that absence of significant increase in mortality in the neonatal period could be because of the protective effect of acquired maternal immunity (Bourne, Thompson, Brody *et al.* 2009).

In summary, HIV/AIDS is not a major direct cause of death for children in the neonatal period.

3 METHOD OF ANALYSIS

This chapter discusses the methods used for assessing the IGME methods and results. Sections 3.1 and 3.3 discuss the method of empirical and logical assessment of the under-five, infant and neonatal mortality rates. Section 3.2 presents the method used for assessing the IGME infant and neonatal mortality rates for consistency with the age pattern of mortality below five years of age.

3.1 Methods of assessing the under-five mortality and infant mortality rates

This study assesses the infant and neonatal mortality rates produced by the IGME for countries such as Botswana, South Africa and Malawi (Malawi was chosen because it is a country having high background mortality, high HIV prevalence and thought to be on track to meet millennium development goal 4, unlike the above countries according to the IGME results). These rates are computed from the under-five mortality rates estimated by the IGME and hence if errors exist in the under-five mortality rates they will affect the infant and neonatal mortality rates. It is necessary, therefore, to assess the reasonableness of the under-five mortality rates computed by the IGME in these countries.

3.1.1 Empirical assessment of under-five and infant mortality rates

In this study the under-five mortality and infant mortality rates determined by the IGME are compared with the estimates made by other organisations and institutions. The under-five mortality and infant mortality estimates of Botswana, Malawi and South Africa determined by the IGME are compared with the estimates from the United States Census Bureau (USCB), Spectrum 4.46b7, IHME and other published estimates. The estimates of under-five mortality and infant mortality rates made by the IHME for South Africa corresponding to periods of high mortality of children due to HIV/AIDS, aren't compared to those of IGME since the IHME apparently used the vital statistics data of South Africa without adjusting for incompleteness and hence the results are misleading (Kerber, Tuaone-Nkhasi, Dorrington *et al.* 2012). In addition, the IGME under-five mortality and infant mortality estimates of Botswana and South Africa are compared to the estimates obtained from the ASSA2003 (Actuarial Society South Africa 2003 model) of Botswana (the latest ASSA model available for Botswana) and ASSA2008 of South Africa respectively. The ASSA2008 model is not used for producing under-five mortality rates for Botswana since the model is developed using the South African data as an input. The IGME estimates of under-five mortality and infant mortality are not compared with the United Nations Population Division, UNPD estimates since they are not independent of estimates of the IGME group.

The comparison of the IGME under-five mortality and infant mortality estimates with the estimates by other institutions and researchers is made by comparing the magnitude of the under-five mortality and infant mortality rates of the IGME with those of the estimates made by others.

3.1.2 Logical assessment of under-five mortality

The IGME has also made assumptions in correcting the bias in the under-five mortality rate due to HIV/AIDS in full birth history data. This study therefore assesses the reasonableness and the impact of these assumptions on the IGME under-five mortality estimates by reviewing relevant literature. In addition, the IGME ignored the estimates of under-five mortality rates computed from summary birth history data using the indirect technique in the modelling process, because the IGME has not developed a technique for correcting the bias due to HIV/AIDS in these estimates. This study thus assesses the impact of ignoring these estimates on the IGME estimate of under-five mortality. The assessment is made by comparing the direct and indirect estimates of under-five mortality rates computed from DHS and MICS data corrected for the impact of HIV/AIDS. If the indirect estimate is larger than the direct estimate, then the IGME model fitted, excluding the indirect estimate, produce relatively lower estimates of under-five mortality rate and vice-versa. The direct estimates of under-five mortality rates corrected for the impact of HIV/AIDS are obtained from the IGME database and the indirect estimates are corrected for the impact of HIV/AIDS using the Ward and Zaba correction method by taking the prevalence of HIV/AIDS at a time which the estimates refer (Darikwa 2009).

3.1.3 Logical assessment of infant mortality

The IGME interpolates the non-AIDS under-five mortality rates of Botswana, Malawi and South Africa using the “West”, “North” and “West” model life tables, respectively (Spectrum uses “West”, “South” and “UN East Asia” for Botswana, Malawi and South Africa respectively), to produce a life table with the under-five mortality rate that corresponds to the estimated non-AIDS under-five mortality rate, the IMR from this life table is used to get the non-AIDS curve of infant mortality. The infant deaths due to HIV/AIDS determined by UNAIDS are added to the resulting non-AIDS infant mortality to get the final infant mortality estimate. Thus in this study the reasonableness of the UNAIDS estimate of the AIDS under-five and infant mortality are assessed by examining the assumptions made and reviewing relevant literature, and its impact on the resulting infant mortality is determined. Moreover, this study assesses the impact of the assumed life table on the IGME infant mortality rates of these countries. In doing so, the ratio of the infant mortality rates to the under-five mortality rates computed from the model life tables are compared with the ratios computed from projection estimates excluding HIV/AIDS mortality and empirical estimates corresponding to the period of no or low HIV.

3.1.4 Estimation of the infant mortality rate using the Blacker and Brass and Keyfitz models

The infant mortality rate is determined from the under-five mortality rate and neonatal mortality rate using the method proposed by Blacker and Brass (2005) and Keyfitz (1966), although these models are designed for estimating the $l(x)$ values between ages one and five years, and not specifically under the age of one year. These methods require the estimates of the survival curve, $l(x)$ at two different ages in order to determine the values of the coefficients of the equation (refer section 2.4.1 and 2.4.2 for details about the methods). The values of the survival curve at age of one month and 60 months are used in this study to compute the values of the coefficients. Estimates either of the neonatal mortality rate or infant mortality rate can be produced using these models. However, the neonatal mortality rate determined from the infant mortality rate and under-five mortality rate using the models are more sensitive to errors in the infant mortality rate than the infant mortality rate (determined from neonatal mortality rate and under-five mortality rate) to errors in the neonatal mortality rate. Thus the models are used to assess only the infant mortality rates.

The estimates of infant mortality rate computed by the IGME are compared with the estimates determined by using the method proposed by Blacker and Brass and Keyfitz.

3.2 The method of assessment of the age pattern of mortality under five years of age

As the under-five mortality rate (U5MR) declines the concentration of mortality in the early ages of life, especially during infancy, and in the neonatal period increases, and as the infant mortality rate declines the concentration of mortality in the neonatal period also rises, and vice-versa (Andreev 2011; Bicego, Chahnazarian, Hill *et al.* 1991). However, Andreev (2011) argues that the above condition is not always true when the mortality level is very low (if the infant mortality rate is between 0.017-0.022), although it is not the case for the countries included in this study. The neonatal mortality rates (NMRs) and infant mortality rates (IMRs) determined by the IGME method for the countries included in this study are assessed by computing the ratio of NMR to U5MR, IMR to U5MR and NMR to IMR. Then the ratios of NMRs to U5MRs, IMRs to U5MRs together with the U5MRs computed by the IGME are plotted against the time to which the estimates refer. The ratios of NMRs to IMRs together with the IMRs determined by the IGME are also plotted against time. The plots are then assessed in order to see if the estimates of NMR and IMR determined by the IGME are consistent with the theory of the age pattern of mortality below five years of age.

3.3 The method of assessment of the neonatal mortality rate

3.3.1 Empirical assessment of the neonatal mortality rate

The IGME estimates of neonatal mortality for Botswana, Malawi and South Africa are compared with estimates produced by other organisations and institutions. These mortality rates estimated by the IGME for countries under-study are also compared with the estimates obtained from the literature. Besides this, the IGME estimates of neonatal mortality rates for South Africa are compared with those of the estimates computed from the vital statistics data corrected for the level of completeness. The same procedure as in the case of under-five mortality and infant mortality rates is carried out to compare the neonatal mortality rates.

3.3.2 Logical assessment of the neonatal mortality rate

According to the IGME, the neonatal mortality rate is expressed as a quadratic function of the under-five mortality rate. However, HIV/AIDS which is one of the major cause of death causes of death for children between one month and five years is not a major direct cause of death for neonates (Lawn, Kerber, Enweronu-Laryea *et al.* 2010; Lawn, Wilczynska-Ketende and Cousens 2006). Thus the reasonableness and impact of relating the under-five and neonatal mortality rates are assessed by reviewing relevant literature.

4 RESULTS

This chapter discusses the consistency of the IGME results of Botswana, Malawi and South Africa with other empirical results. Moreover, the reasonableness and the impact (on the IGME results) of the assumptions made in developing the IGME method are also discussed. Section 4.1 presents the comparison of the IGME under-five mortality rates of Botswana, Malawi and South Africa with other empirical results determined by different institutions, organisations and published results, and an assessment of the reasonableness and the impact of the assumptions made by the method in estimating the under-five mortality rates (logical assessment). Section 4.2 discusses the age pattern of mortality below the age of five years. The empirical and logical assessment of the infant and neonatal mortality rates are discussed in section 4.3 and 4.4.

4.1 Assessment of the under-five mortality rate

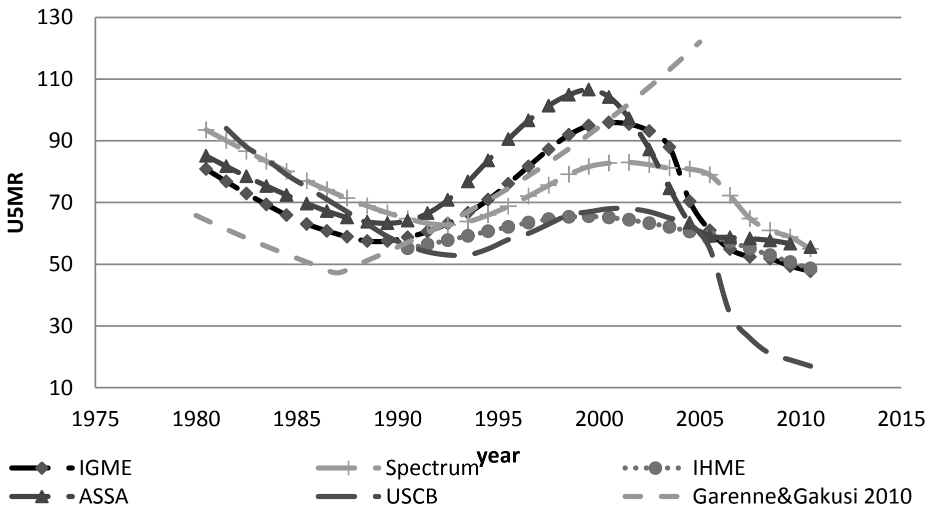
4.1.1 Empirical assessment of the under-five mortality rate

4.1.1.1 Empirical assessment of the Botswana under-five mortality estimates

The under-five mortality rates of Botswana produced by the IGME are compared with other empirical estimates, shown in Figure 4.1. According to this comparison the under-five mortality rates of Botswana produced by the IGME are not significantly different from other empirical estimates except those determined by Garenne and Gakusi (2009) between 1980 and 1990. After 1990, while the IGME estimates increase rapidly and the deviation of the IGME results from those of the Spectrum, USCB and the IHME results get bigger with time, the IGME results on average approach the estimates determined by Garenne and Gakusi (2009) and the ASSA2003 estimates between 1990 and 2002 (the IGME results increase from about 57 to 93 and those of the Spectrum, IHME and USCB increase from 64 to 82, 55 to 63 and 56 to 67 respectively in the same period as shown in Table B 1, Appendix B). The estimates of the ASSA2003 model may be exaggerated because of the fact that the model is somewhat out of date (personal communication with Rob Dorrington). Specifically, the IGME results are on average close to those of the ASSA2003 estimates between 1998 and 2002 in contrast to other estimates, which could suggest that the IGME results are overestimated during this period. This could be because the method used by IGME to produce these results ignore the impact of PMTCT which has had significant impact on the improvement of survival of children over the years following the start of the programme (UNAIDS and

NACA 2010) or the estimation of the AIDS mortality by UNAIDS estimate. Beginning from 2003 the IGME estimates approach the estimates produced by others except the USCB and thus these results seem reasonable. In conclusion, the IGME under-five mortality rates of Botswana are consistent with other estimates between 1980 and 1997 and after 2002, but are possibly too high between 1998 and 2002.

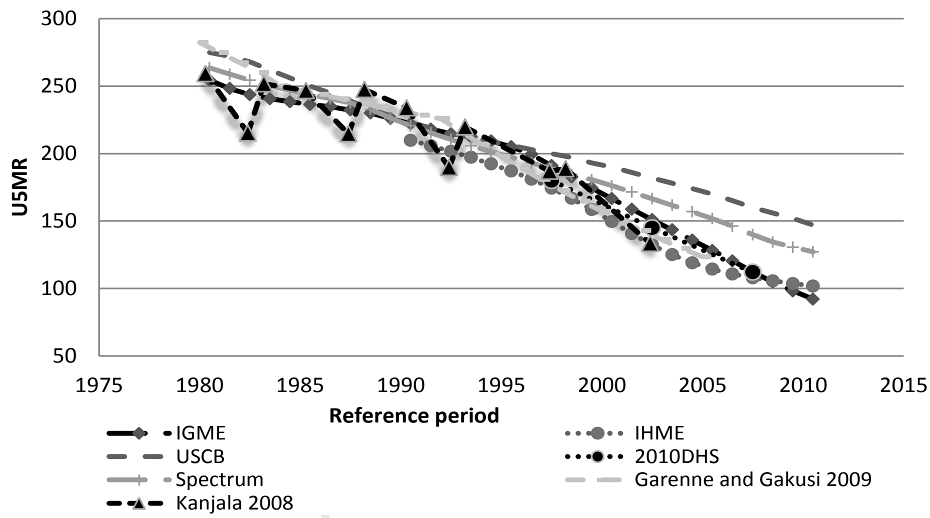
Figure 4.1 Plot of the of U5MR by others to IGME estimates for Botswana



4.1.1.2 Empirical assessment of the Malawian under-five mortality estimates

Figure 4.2 shows the plot of the under-five mortality rates of Malawi obtained from different sources including estimates of Kanjala (2008) computed from the 1992, 2000 and 2004 DHS full birth history data without correcting for the bias due to HIV/AIDS and the estimates obtained from the 2010 DHS report. According to this comparison, the IGME estimates are consistent with the estimates determined by others until 1998. However, the under-five mortality rates produced by the IGME from 1980 to 1998 are less than or equal to (lie between 214 and 182, shown in Table B 1, Appendix B) the under-five mortality rates computed from full birth history data not corrected for the bias due to HIV/AIDS (which are between 219 and 188). On the other hand, the prevalence of HIV in Malawi among women aged 15-49, obtained by standardising the ANC data for area and age is above 10%, according to Crampin, Glynn, Ngwira *et al.* (2003) and 9.5% according to Spectrum, since 1992. The under-five mortality rates computed from full birth history data without correcting the bias due to HIV/AIDS underestimate the true rates (Mahy 2003; Zaba, Marston and Floyd 2003). Therefore, the IGME under-five mortality rates of Malawi produced between 1992 and 1998 appear to be too low since they lie below the estimates computed from full birth history data without correcting for the bias due to HIV/AIDS. Starting from early 2000 the difference between the IGME estimates and the estimates produced by the USCB and Spectrum gets bigger with time and the IGME results approach to the estimates obtained from the 2010 DHS (the IGME estimates are higher by 6%, 4% and 0.3% compared to the 2010 DHS estimates in the periods 10-15, 5-10 and 0-5 years before the survey, respectively), which suggests that the IGME results are probably understated to a certain extent between 1999 and 2010.

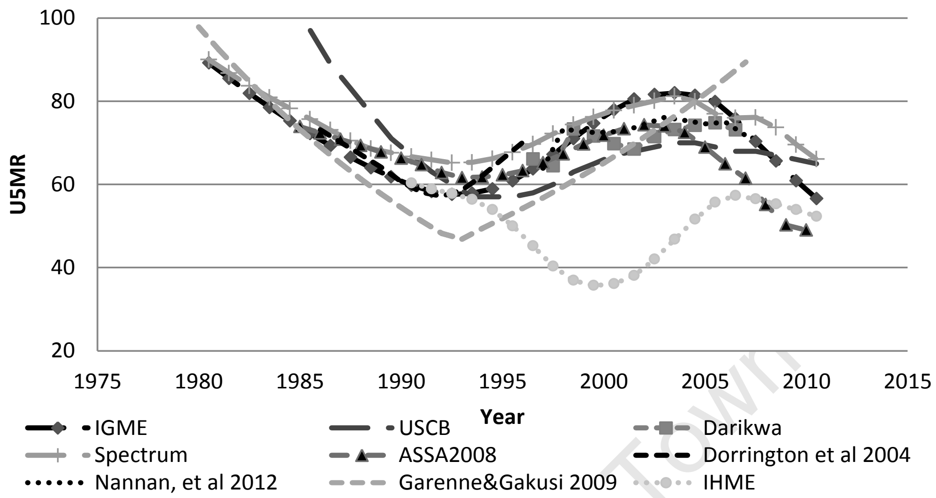
Figure 4.2 Plot of the U5MR estimated by IGME and others for Malawi



4.1.1.3 Empirical assessment of the South African under-five mortality estimates

Figure 4.3 shows the plot of the South African under-five mortality rates obtained from different sources, including those obtained from from the IHME (the quality of the 2003 DHS data of South Africa is poor hence not used for assessing the IGME results). From this comparison the under-five mortality rates estimated by the IGME are close to the estimates produced by others between 1980 and 1993. Thereafter, the under-five mortality produced by the IGME increase at a faster rate and lie above the ASSA2008 model estimates and empirical results computed by Darikwa (2009) and Nannan, Dorrington, Laubsher *et al.* (2012) from vital registration data corrected for incompletness, between 2000 and 2006. This could be due to errors in the data used for computing empirical results and the estimation of the AIDS mortality obtained from UNAIDS. However, the IGME under-five mortality rates do not deviate significantly from those of the ASSA2008 model and empirical estimates (deviates by 1% - 16% and 1% - 9.6% from the ASSA2008 and empirical estimates respectively). Starting from 2007 the under-five mortality rate produced by the IGME lie between the estimates made by projection models and do not deviate significantly from the results of these models. Generally, the estimates of South African under-five mortality rates produced by the IGME are consistent with the other empirical estimates.

Figure 4.3 Plot of the IGME U5MRs together with the estimates by others for South Africa



Thus generally, from the above comparisons it appears that the IGME estimates for South Afrca and Botswana are consistent with other empirical results except those of the estimates of Botswana between 1998 and 2003. The under-five mortality of Malawi produced by the IGME consistent with epirical results determined by others during periods of no or low HIV/AIDS epidemic (before 1992), afterwards the estimates appear to be biased downward. The reason is not apparent. It could be because the method used for correcting the bias in the under-five mortality rate due to HIV/AIDS computed from full birth history data may not work in countries like Malawi having high background mortality (mortality due to all other causes except AIDS) and/or errors in the data.

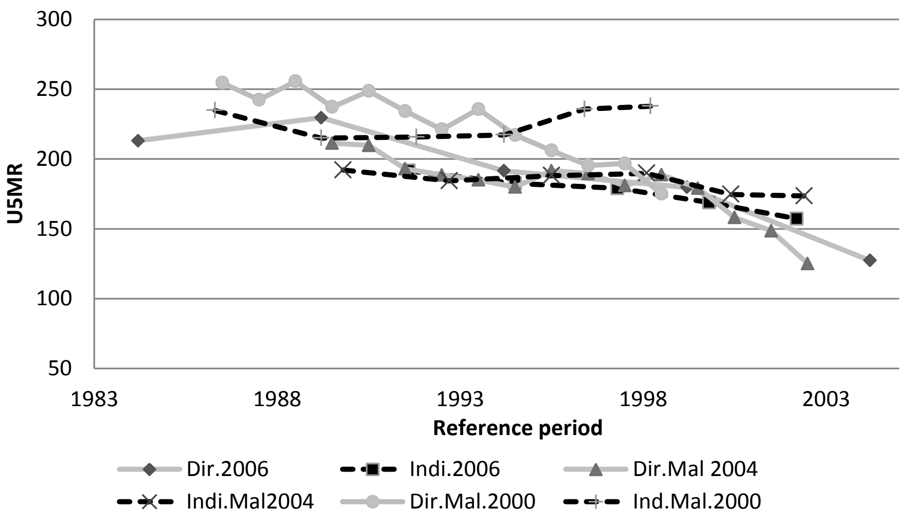
4.1.2 Assessment of the impact of excluding the indirect under-five mortality rates by the IGME

This section discusses the impact of IGME having excluded the indirect under-five mortality rates in the modelling process, on the under-five mortality produced for Malawi and South Africa. Botswana is not considered since it was not possible to get both the direct and the indirect under-five mortality rates computed from the same data source during the period of HIV epidemic.

4.1.2.1 Comparison of the direct and the indirect under-five mortality rates of Malawi

The comparison of the direct under-five mortality rates corrected for the impact of HIV using the IGME (Hill and Walker) method, with the indirect under-five mortality rates corrected for the impact of HIV using the Ward and Zaba's method, crudely adjusted (by taking the prevalence of HIV/AIDS at a time which the estimates refer) to allow for changes in the prevalence of HIV over time for Malawi, is shown in Figure 4.4. According to this figure, the direct and the indirect under-five mortality rates computed from the 2004 DHS and the 2006 MICS using the data from women in the middle of the reproductive age range are relatively close. However, there are notable differences between the under-five mortality rates determined using the direct and the indirect methods using the data from women at the youngest and oldest reproductive age groups. The discrepancy between the under-five mortality rates estimated using the direct and the indirect methods at the youngest and the oldest age groups could be due to biases in the data obtained from women in these age groups. Accordingly, the IGME assigns low weight to the under-five mortality rates computed using the data obtained from women in these age groups. However, there is a significant difference between the direct and the indirect under-five mortality rates computed from the 2000 DHS data. The direct estimates show a declining trend, which is consistent with other studies (Garenne and Gakusi 2009; Kanjala 2008), whereas the indirect estimates are virtually stable between 1989 and 1994 and increase after that. It is possible that this difference can be due to errors associated with the data used for computing the indirect estimates. Hence there is no significant difference between the direct and the indirect under-five mortality rates of Malawi. Thus, one cannot fault the IGME under-five mortality rates of Malawi for excluding the indirect under-five mortality rates corresponding to the period of high HIV/AIDS epidemic in the estimation process.

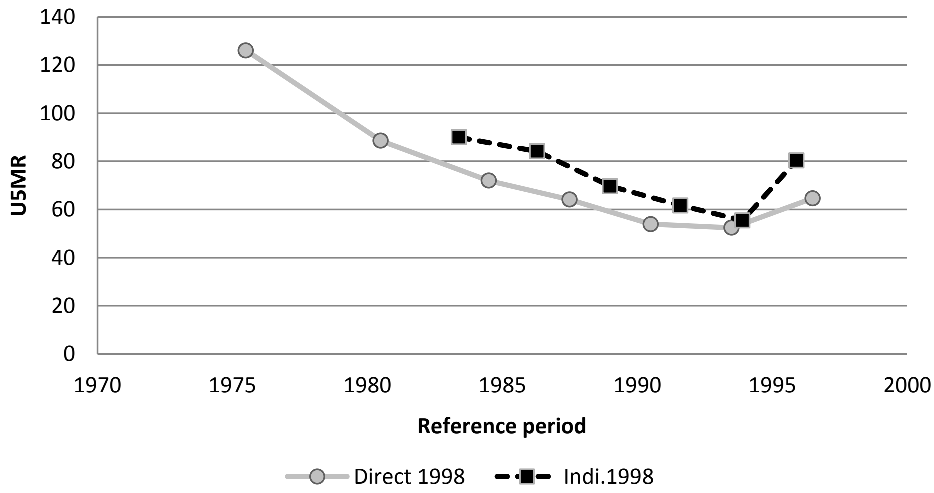
Figure 4.4 The direct and the indirect U5MRs corrected for the impact of HIV for Malawi



4.1.2.2 Comparison of the direct and the indirect under-five mortality rates of South Africa

The indirect under-five mortality rates computed from the 1998 SADHS, crudely adjusted for the impact of HIV/AIDS using Ward and Zaba method, are higher than the corresponding estimates computed from the 1998 SADHS full birth history data, as shown in Figure 4.5 (the 2003 SADHS is excluded due to error in the data). This is because the Brass CEB/CS method overestimates the under-five mortality rates for countries having longer birth intervals, such as South Africa (Dorrington, Timaeus, Moultrie *et al.* 2004; Nannan, Timaeus, Laubscher *et al.* 2007). Thus the exclusion of the indirect under-five mortality rates of South Africa in the modelling process by the IGME probably resulted in better estimates.

Figure 4.5 The 1998DHS direct and indirect U5MRs corrected for the impact of HIV for South Africa



4.1.3 Logical assessment of the under-five mortality rate

The IGME makes some assumptions in order to correct the bias introduced due to HIV/AIDS on the estimates of under-five mortality rates computed from full birth history data. The accuracy of the under-five mortality rates computed from full birth history data for countries affected by HIV/AIDS in general and Botswana, Malawi and South Africa in particular depend on these assumptions. The reasonableness and/or the impact of these assumptions are discussed in this sub-section.

The method used by the IGME to produce these results assumes that 35 per cent of the births of HIV positive mothers are HIV-positive. This is the transmission rate of the virus from the mother to the child without PMTCT or ART (Department of Health South Africa 2012; NACA 2008). Thus the IGME method effectively assumes that the PMTCT programme doesn't have an impact on child survival in general and on the transmission of the virus from the mother to the child in particular. A study conducted in Kwazulu-Natal, South Africa by Rollins, Little, Mzolo *et al.* (2007) indicates that the transmission rate of HIV from mother to the child among women who use the PMTCT programme (use of single dose nevirapine) is less than 50% of women who do not. A report by the Department of Health South Africa (2012) reveals that as a result of the use of single dose nevirapine the national transmission rate of HIV reduced from a value 30% (in the absence of PMTCT) in 2001 to 12% in 2007. Another study conducted in Botswana by Stover, Johnson, Zaba *et al.* (2008) suggests that PMTCT resulted in a 66% reduction in the number of new infections in 2007 as compared to the number expected if the programme wasn't introduced. According to reports (NACA 2008; UNAIDS and NACA 2010), in Botswana the PMTCT programme was established in 1999 and the percentage of HIV positive women using PMTCT rose from 27% in 2002 to 94% in 2009. Therefore the failure to take into account the impact of the PMTCT programme produces an exaggerated number of children infected by HIV in Botswana. Thus the number of deaths of children due to HIV may be inflated, which correspondingly overstates the estimated number of unreported child deaths due to deaths of mothers because of HIV/AIDS. The direct under-five mortality rates (adjusted for the bias due to HIV) computed from the 2007 Botswana Family and Health Survey data could be exaggerated and may in turn overstate the IGME under-five mortality rates especially, those in the early 2000s. The South African PMTCT programme was implemented at the national level during 2002 and the percentage of women using PMTCT reached 72% in 2006 (Frizelle, Solomon and Rau 2009; Ministry of Heath South Africa 2008). However, since the IGME did not use any direct under-five mortality rates computed from full birth history data after 2003, ignoring the impact of PMTCT does not affect the IGME results. The PMTCT programme of Malawi was launched in 2003 and the uptake was low up to 2007 (Ministry of Health Malawi 2008). Hence the assumption of no impact of PMTCT may not exaggerate the estimate computed from the 2010 DHS survey referring the period 0-4 years before the survey date. This is because the PMTCT programme was expanded after 2007 and the survival of HIV-positive women who gave birth during this period was high. Hence the estimated number of unreported deaths of children due to death of their mothers because of HIV/AIDS is limited. Therefore, the IGME under-five mortality rates of Malawi are not affected as a result of not taking into account the impact of PMTCT programme.

The IGME also assumes that the mortality experience of HIV negative births is the same whether the children are borne by HIV-positive or HIV-negative mothers. However, studies indicate that HIV-negative births to HIV-positive mothers have a higher chance of dying than births from HIV-negative mothers (Adetunji 2000; Hallett, Gregson, Kurwa *et al.* 2010; Marston, Zaba, Salomon *et al.* 2005; Nakiyingi, Bracher, Whitworth *et al.* 2003). This is because of the indirect impact of HIV, such as the mother being sick or dead, on the survival of children of HIV-positive mothers. If we consider one impact, such as death of the mother, the likelihood of death of children less than three years old whose mothers have died is 6 times higher as compared to their counterparts, and the probability of dying of HIV-positive mothers is 12 times higher as compared to HIV-negative mothers (Zaba, Whitworth, Marston *et al.* 2005). In addition, a study conducted in Uganda by Newell, Brahmbhatt and Ghys (2004) suggests that there is a significant difference in mortality between HIV-negative children born to HIV-positive and HIV-negative mothers (166 and 128 per 1000 respectively). Hence the assumption (i.e. the mortality of HIV-negative children born to HIV-positive and negative mothers is similar) may understate the under-five mortality rates. However, this effect may be confined to periods of high HIV prevalence (above 10%) with no or limited use of ART. The ART programme was introduced to Botswana in 2001 and the percentage of people on ART reached 63% among those in need of ART during 2004 (Campbell, Kereng, Malmborg *et al.* 2012). The Malawian and South African national ART programme rolled-out in 2004. In Malawi the percentage of people on ART among those in need reached 61% by 2006 (Harries, Zachariah, Jahn *et al.* 2009) and in South Africa it was expected to reach around 50% in 2008 (Nattrass 2006). Therefore, the IGME estimates for Botswana between 1994 and 2004, Malawi between 1993 and 2005 and South Africa 1997 and 2007 could be understated.

In addition, the IGME assumes that the under-five mortality rate of HIV-positive births is 0.625 irrespective of whether the infection occurred before or at delivery (perinatally) or through breastfeeding. However, the progression of the disease depends on the point at which the child becomes infected. Children infected perinatally have a much higher risk of dying than those infected postnatally (Marston, Becquet, Zaba *et al.* 2011; Stover, Johnson, Hallett *et al.* 2010). Similar studies also indicate that the hazard of children dying from being infected with HIV before or at birth is more than two times of those infected postnatally (Becquet, Marston, Dabis *et al.* 2012; Fawzi, Msamanga, Hunter *et al.* 2000; Krist and Crawford-Faucher 2002; Newell, Coovadia, Cortina-Borja *et al.* 2004; Ngubane, Ndirangu, Newell *et al.* 2012). In addition, the assumption does not consider the impact of child treatment (use of ART and Cotrimoxazole) on the reduction of the mortality of HIV positive children until 2007. According to a study by Stover, Fidzani, Molomo *et al.* (2008) in Botswana, deaths of children due to HIV/AIDS have reduced from 3,000 in 2001 to 790 in 2007 as a result of using ART on HIV-positive children. Thus the number of deaths of children due to HIV/AIDS could be inflated since the impact of treatment of children is ignored. Accordingly, the under-five mortality rates computed from full birth history data corrected for the bias due to HIV/AIDS may be overstated. Since the IGME model is fitted from these estimates, the under-five mortality rates produced by the IGME model could be exaggerated.

A survival curve with median survival time of 9.5 years since infection obtained from cohort studies is used by the IGME in order to determine the mortality schedule of women 4 years after infection for all countries with general epidemic level. However, studies by Stover, Johnson, Zaba *et al.* (2008) and Isingo, Zaba, Marston *et al.* (2007) show that the median survival time of females since infection without the use of ART is about 11.5 years for most countries including those in Southern Africa. Moreover, the study by Isingo and others suggests that the median survival time of women is strongly correlated with age at infection with a hazard ratio of death of 1.06 as age increases by one year. A similar study conducted in Malawi suggests the median survival time of women infected in age groups 15-19, 20-24, 25-29, 30-34, 35-39, 40-44 and 45-49 is 13.3, 12.8, 11.7, 10, 9.1, 8.4, and 6.6 respectively in the absence of ART (Shapira 2011). In addition, the probability of survival of women is significantly improved after they receive ART (de Olalla, Knobel, Carmona *et al.* 2002; Kitahata, Gange, Abraham *et al.* 2009; Mahy, Lewden, Brinkhof *et al.* 2010; Rehle and Shisana 2003; UNAIDS and WHO 2009) and hence the average survival after the onset of AIDS increases from four months to 50 months (Kilsztajn, Lopes, do Carmo *et al.* 2007). The under-five mortality rates corrected for the bias due to HIV/AIDS are determined from full birth history data assuming a median survival time of 9.5 years (the IGME assumption) and 11.5 years using the IGME spreadsheet (developed by Hill and Walker and given to me by Rob Dorrington) in order to see if there is a significant difference between the under-five mortality rates computed under the two assumptions. The under-five mortality rates prior to 5-9 and 10-14 years to the survey date (assuming the survey is conducted in 2009) determined using the IGME assumption are higher by 8% - 10% and 5% - 11% respectively as compared to those produced using a median survival time of 11.5 years.

Therefore, the above assumption (median survival time of 9.5 years) could inflate the under-five mortality rates produced by the IGME.

4.2 Assessment of the age pattern of mortality below the age of five years

The ratios of the IMR to U5MR and NMR to U5MR are expected to rise when the U5MR declines and decline when the U5MR increases for Botswana and South Africa, according to Figure 4.6 and Figure 4.7 respectively. Thus as the under-five mortality rate declines the concentration of mortality in the infant and neonatal period rises and vice-versa. Therefore, the IGME estimates of neonatal, infant and under-five mortality rates of Botswana and South Africa are consistent with the theory of the age pattern of mortality below five years of age.

Figure 4.6 Plot of ratio of IMR and NMR to U5MR together with U5MR for Botswana

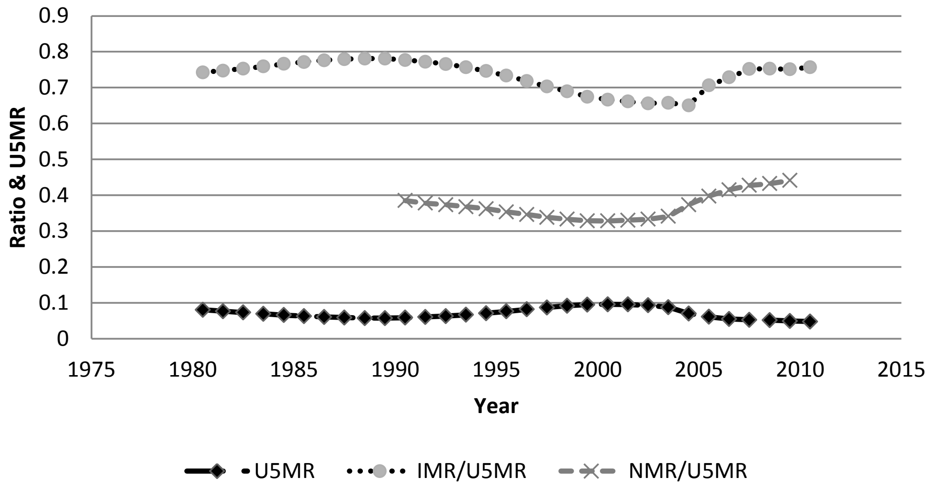
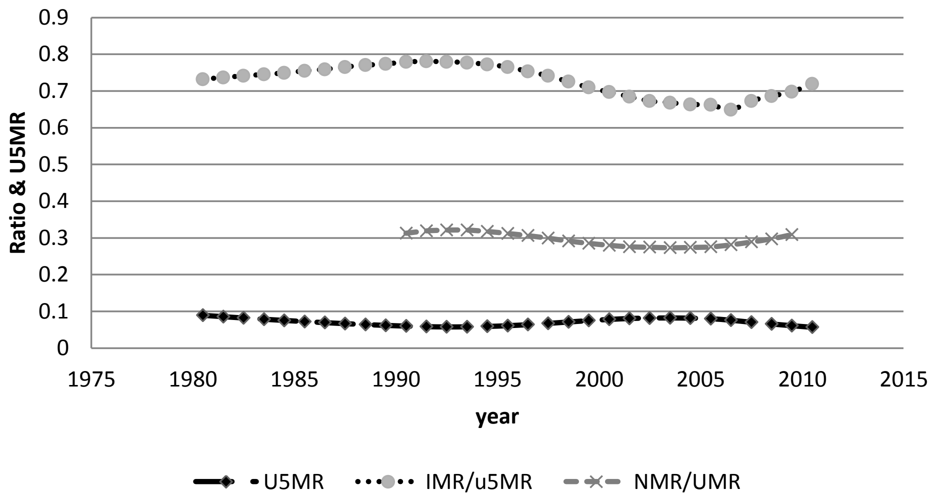
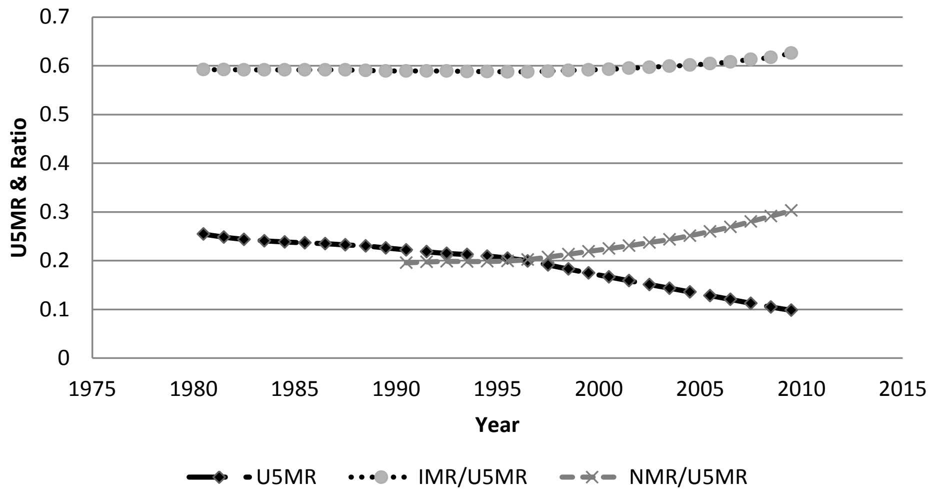


Figure 4.7 Ratio of IMR and NMR to U5MR together with U5MR for South Africa



The under-five mortality rate of Malawi is declining almost linearly over the period of observation and hence one would expect a rising trend for the ratio of IMR to U5MR and NMR to U5MR. However, the ratios remained virtually constant up to 1995 and declined thereafter, as presented in Figure 4.8. The reason for having constant ratios up to 1995 could be because of the fact that when mortality is high the ratios may not necessarily rise following the decline in the under-five mortality. For example, Coale and Demeny suggests a constant value for ${}_1a_0$ and ${}_4a_1$ when the mortality is high (Andreev 2011). Therefore, we cannot say that the IGME estimates are inconsistent with the theory of the age pattern of mortality.

Figure 4.8 Ratio of IMR and NMR to U5MR together with U5MR for Malawi



The IGME infant and neonatal mortality rates are also checked to see if they are consistent with the theory of the age pattern of mortality, shown in Figure 4.9, Figure 4.10 and Figure 4.11 respectively. According to the figures, a decrease in infant mortality rate is accompanied by a corresponding increase in the concentration of mortality in the neonatal period and vice-versa. Thus the IGME neonata mortality and infant mortality rates are consistent with the theory of the age pattern of mortality below one year of age. The reason for a strange jump of the ratio of NMR to IMR in 2004 -2005 for Botswana, shown in Figure 4.9, is not apparent however it could be due to a faster rate of redution in IMR as result of the use of ART and PMTCT as compared to NMR (which reduces at a slower rate and HIV is not a major direct cause of death).

Figure 4.9 Ratio of NMR to IMR together with IMR for Botswana

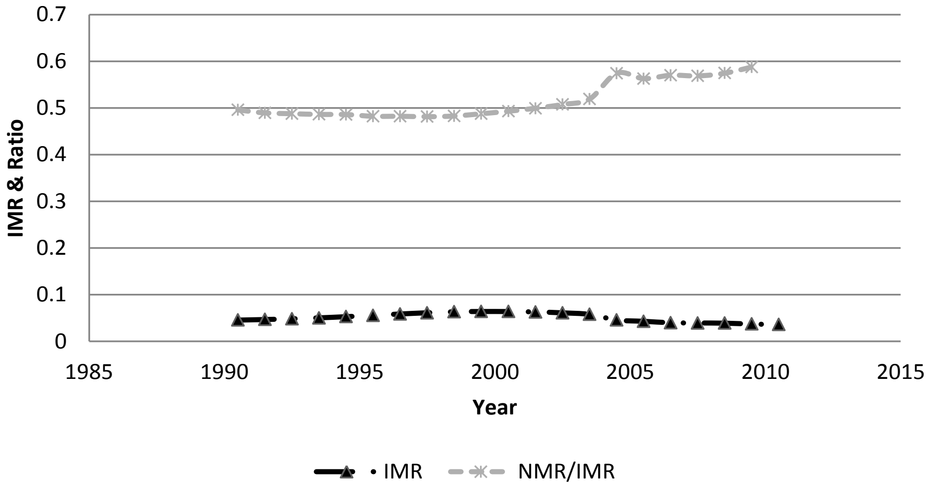


Figure 4.10 Ratio of NMR to IMR together with IMR for Malawi

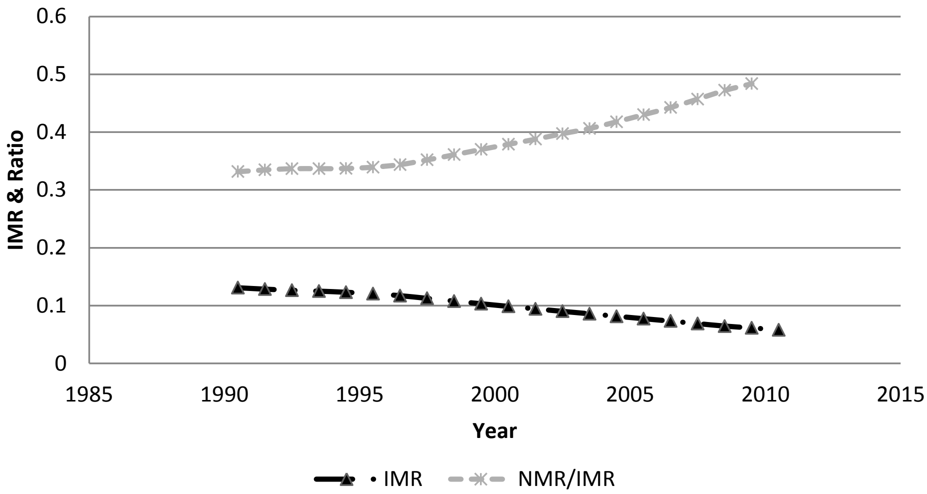
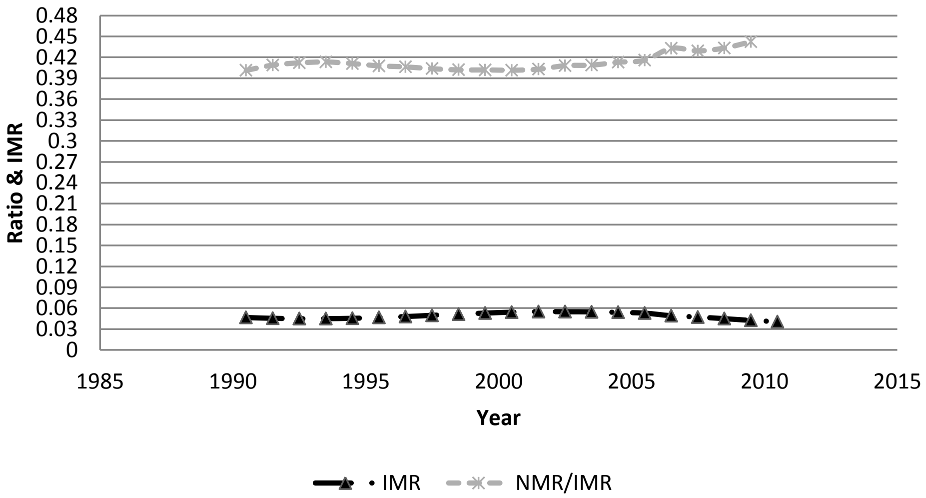


Figure 4.11 Ratio of NMR to IMR together with IMR for South Africa



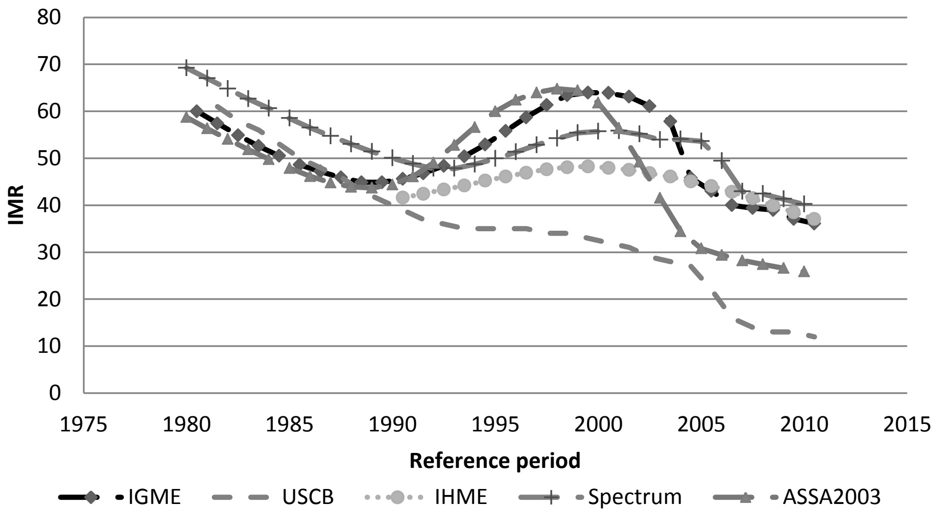
4.3 Assessment of the infant mortality rate

4.3.1 Empirical assessment of the infant mortality rate

4.3.1.1 Empirical assessment of the infant mortality rates of Botswana

As can be seen from Figure 4.12, the infant mortality rates computed by the IGME are close to the estimates determined by others, especially to the estimates of USCB and ASSA2003 of Botswana between 1980 and 1989. After that, as in the case of the under-five mortality rate, the IGME infant mortality moves together with the ASSA2003 estimates (a model that may produce higher deaths since it is out of date) up until 1999 and lie above all estimates produced by others between 2000 and 2003. The IGME result deviates from those of the IHME by 28% - 33% and Spectrum by 7% - 17%, and is higher especially between 1996 and 2002 (the IGME results are between 58 and 64 while those of the IHME, USCB and spectrum are between 46 and 48, 35 and 29 and 51 and 55 in the period, shown in Table B 2, Appendix B). Hence the estimates seem exaggerated in the specified period, which could be because it is estimated from the under-five mortality rate (U5MRs are exaggerated during this period) and/or the use of the UNAIDS model to estimate the number of infant deaths due to HIV. After 2003 the IGME estimates are fairly close to those from the IHME and Spectrum and the estimates are probably reasonable. In conclusion, the IGME infant mortality rates are consistent with other estimates between 1980 and 1996 and after 2003, but are possibly too high between 1996 and 2003.

Figure 4.12 Plot of the IMR estimates by the IGME and others for Botswana

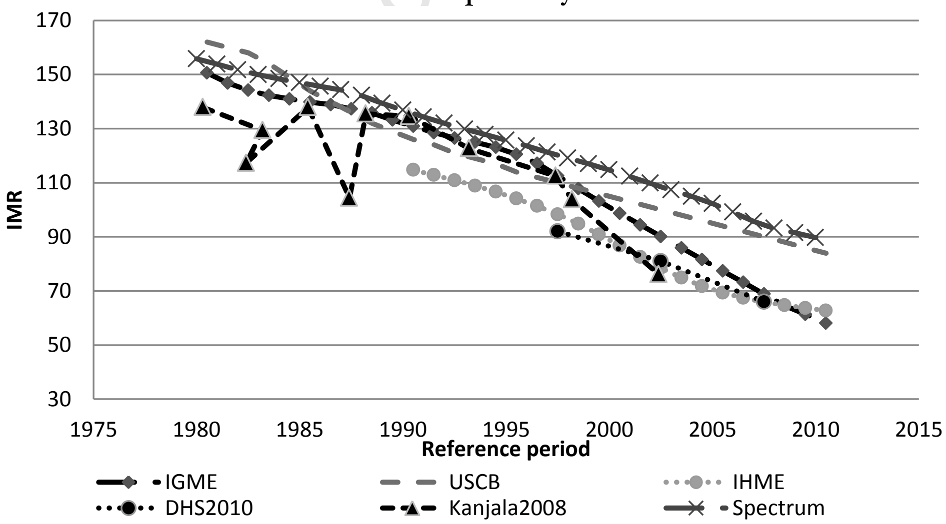


4.3.1.2 Empirical assessment of the infant mortality rates of Malawi

The infant mortality rates of Malawi determined by the IGME are fairly close to the estimates produced by others between 1980 and 1998, as shown in Figure 4.13 and

Table B 2, Appendix B. The IGME results (lie between 139 and 107) are also virtually the same as those of the estimates computed from full birth history data not corrected for the impact of HIV (which are between 137 and 103) by Kanjala (2008) between 1985 and 1998. Studies (Mahy 2003; Zaba, Marston and Floyd 2003) indicate that the IMRs determined from full birth history data not corrected for the impact of HIV/AIDS are biased downward. Therefore, the infant mortality rates determined by the IGME between 1992 and 1998 are low (on average lower by 10%) since the prevalence of HIV/AIDS in Malawi among women in the childbearing age group is above 9.5 beginning from 1992, according to the estimates obtained from Spectrum and a study by Crampin, Glynn, Ngwira *et al.* (2003). The reason for low value of IMR in the specified period could be because of the estimation of the infant mortality rate from the under-five mortality rate, which is biased downward. Since 1998 the deviation of the IGME results from those of the USCB (8%-44% between 1998 and 2010) and Spectrum (18%-54% between 1998 and 2010) increase with time, and on average, the IGME results are close to the results of Kanjala (2008) and the 2010 DHS report (estimates not corrected for the impact of HIV) especially after 2006 and the IHME. Thus the estimates appear to be low from 2007 onwards.

Figure 4.13 Plot of the IMR estimates computed by the IGME and others for Malawi

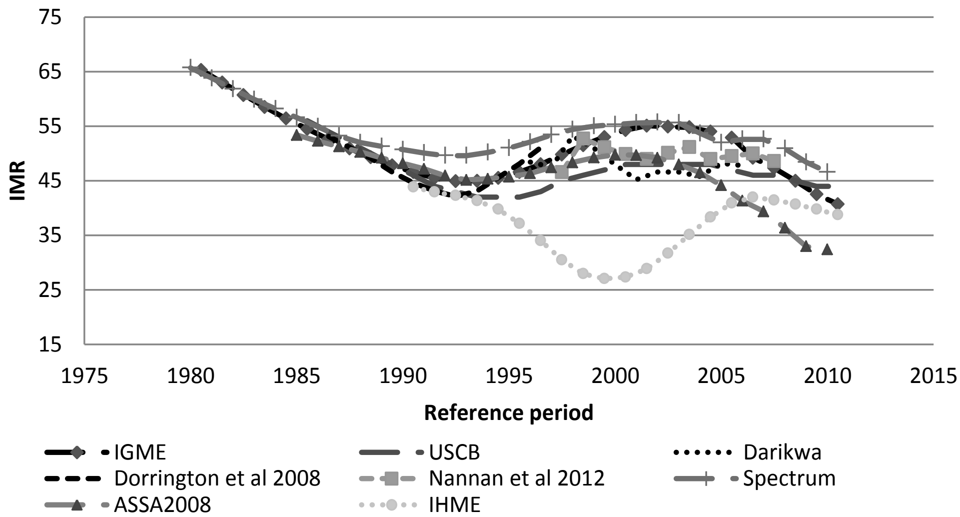


4.3.1.3 Empirical assessment of the South African infant mortality rates

Figure 4.14 compares the South African infant mortality rates estimated by the IGME with estimates produced by others. According to this comparsion, the infant mortality rates estimated by the IGME are very close to the estimates produced by others between 1980 and early 1990s. After that, the infant mortality rates rise, becoming close to the Spectrum results, and although insignificant, the IGME results differ by 9%-16%

from the ASSA2008, 8%-12% from those estimates computed from vital statisitics data after adjusting for incompletness by Nannan, Dorrington, Laubsher *et al.* (2012) and 6-13% from those estimates produced by USCB between 2000 and 2005. This could be because of the estimation of the infant mortality due to HIV from UNAIDS and/or due to errors in the data used for computing empirical results. Thereafter, the IGME estimates declined and become close to the other estimates except the ASSA2008 (which could be because the ASSA2008 model assumes a higher rate of reduction of the transmission of the virus from the mother to child or the consideration of the impact of the impact of information and education campaigns and social marketing and treatment of STDs by the ASSA model unlike to other models), and hence the IGME estimates may be considered to be consistent with other empirical results.

Figure 4.14 Plot of the South African IMR estimated by IGME and others



In conclusion, based on the above comparsions the infant mortality rates produced by the IGME for Botswana and South Africa appear to be reasobale except the estimates for Botswana between 1996 and 2002. The Malawi infant mortality rates produced by the IGME are consistent with other empirical estimates before 1990 and between 1999 and 2005, in the other periods the estimates appear to be biased downward.

4.3.2 Comparison of the IGME infant mortality rates with estimates computed using the Blacker and Brass and Keyfitz methods

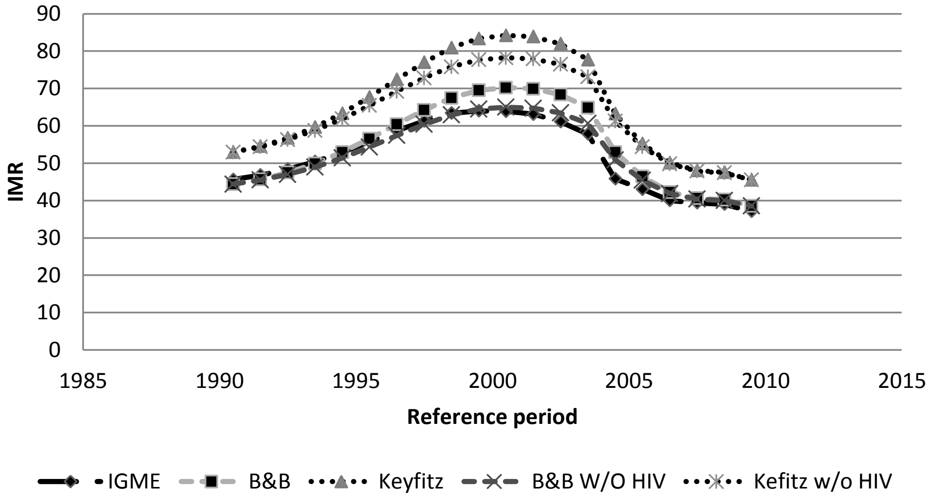
This section discusses the comparison of the IGME results with those of the infant mortality rates determined from the neonatal mortality rates and under-five mortality rates using the Blacker and Brass and Keyfitz model for Botswana and South Africa. Malawi is not included since the relative comparison of infant mortality rate to under-five mortality rate is low in the country unlike for South Africa and Botswana. According to Blacker and Brass (2005), when mortality is relatively lower during infancy than during childhood the model may not give accurate results (which is what the results (not shown) of Malawi showed).

4.3.2.1 *Comparison of the IGME infant mortality rates of Botswana with estimates computed using the Blacker and Brass and Keyfitz models*

The IGME infant mortality rate of Botswana and those estimated from the neonatal mortality rate (after removing the HIV trend in the neonatal mortality rate, see section 4.4 for further detail) and under-five mortality rate using the Blacker and Brass and Keyfitz models are compared in Figure 4.15. According to this comparison, the IGME results are fairly close to those of the infant mortality rates determined using the Blacker and Brass model. The IGME infant mortality rates are also compared with those estimates of infant mortality rates determined using the Blacker and Brass model without removing the HIV trend in the neonatal mortality rate; the IGME results are very close to those determined by using the model except during the period of high mortality of children due to HIV/AIDS, suggesting that the IGME neonatal mortality rates are likely to be inflated 1998 and 2003.

The IGME results lie significantly below (16-33% less) the results determined using the Keyfitz model, not only for Botswana but also for South Africa (not shown) (and hence this model was dropped from consideration for South Africa Figure 4.16), which could be due to the inappropriateness of that model in estimating the infant mortality rate from neonatal mortality rate and under-five mortality rate. Thus based on the above results the IGME estimates are consistent with those produced by Blacker and Brass model.

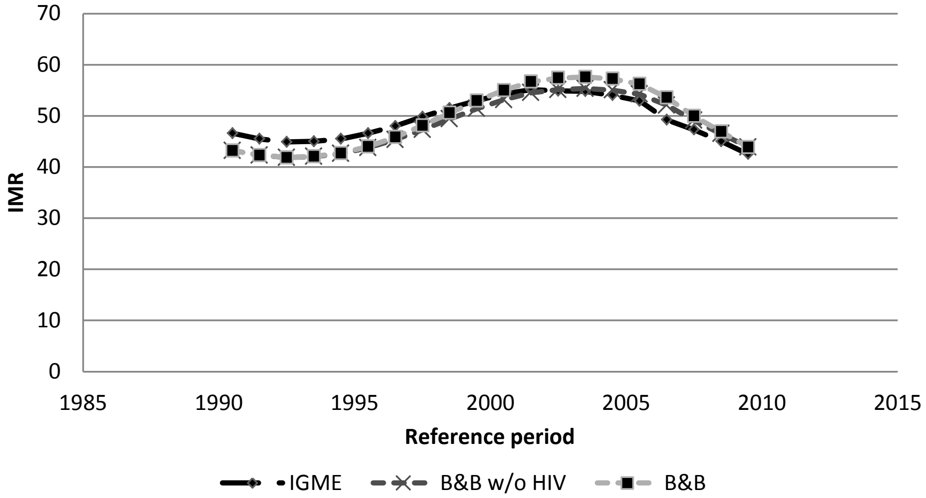
Figure 4.15 The IMR determined by the IGME and using the Blacker and Brass and Keyfitz models for Botswana



4.3.2.2 Comparison of the South African infant mortality determined by the IGME with the results computed using the Blacker and Brass model

The South African infant mortality rates produced by the IGME are very similar to those of the estimates computed using the Blacker and Brass model in both scenarios (neonatal mortality rate with and without the HIV trend), although the estimates determined without the HIV trend in neonatal mortality rate are relatively closer, as indicated in Figure 4.16. The fact that the South African IGME estimates are close to the infant mortality rates determined from neonatal mortality rate with the HIV trend during times of high HIV mortality unlike those of Botswana is probably because the South African under-five mortality rates are consistent with other empirical estimates, as discussed in section 4.1.1.3 unlike to those of Botswana in the specified time.

Figure 4.16 The IMRs computed by the IGME and using the Blacker and Brass models for South Africa



In general, according to the above results the infant mortality rates of South Africa and Botswana produced by the IGME appear to be consistent with the estimates determined using the Blacker and Brass model. The Blacker and Brass model works reasonably well in AIDS mortality settings and can give reasonably good results of infant mortality rate, which could be estimated from the neonatal mortality rate and the under-five mortality rate.

4.3.3 Logical assessment of the infant mortality rate

The IGME determines the non-AIDS under-five mortality rate by subtracting the AIDS under-five mortality rate determined by UNAIDS from the all-causes under-five mortality rate. The UNAIDS estimates the AIDS under-five mortality rate using the estimates/projections of the prevalence of HIV among women in the reproductive age group, the age specific fertility rate of HIV infected women, the transmission rate of HIV from the mother to the child and the survival rate of children infected with the virus. The reasonableness of the assumptions made by the UNAIDS to get the values for some of the parameters and the impact of some of these assumptions on the IGME mortality estimates are assessed below.

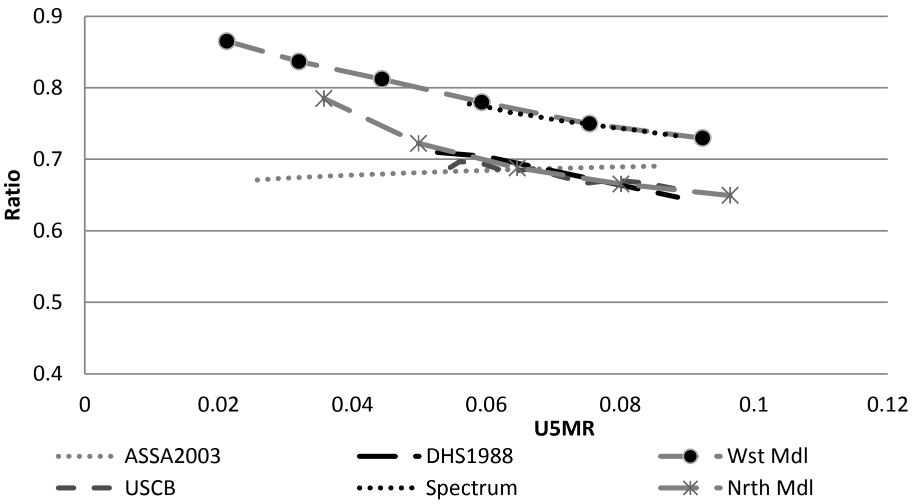
The IGME uses the default Spectrum (4.64 Beta 7) results to estimate the number of children who died of AIDS. The default Spectrum assumes that the annual survival of infants on ART is 0.83 and for children aged one year and above the survival is 0.85 in the first year of use of ART and 0.93 in subsequent years. A literature review conducted by Dabis and colleagues (Mahy, Lewden, Brinkhof *et al.* 2010) in low and middle income countries indicates that the annual chance of survival of infants on ART in the first year of use of ART is between 0.93 and 0.95 and the survival becomes between 0.91 and 0.92 in the second year of ART use. They also conclude that taking Cotrimoxazole together with ART reduced death by 33%, 16% and 1% in the first, second and third year of treatment respectively. As a result, Spectrum allows the user to enter the percentage or number of children using Cotrimoxazole and adjusts mortality accordingly. According to the above discussion and as can be seen from the Spectrum package, the default Spectrum assumes no Cotrimoxazole is provided. However, some countries use Cotrimoxazole, for example, in Botswana the use of Cotrimoxazole by HIV infected children was 5,475, 8,115, 8,830 and 9,858 in 2004, 2005, 2006 and 2007 respectively. Calculating the deaths by entering those numbers in Spectrum and comparing with the deaths determined using the default spectrum results in; 5% - 9% lower in infant mortality and 5% - 6% lower in under-five mortality between 2004 and

2007. Therefore, deaths of children due to HIV produced by the IGME are likely to be overestimated in such situations, which in turn affect the non-AIDS child mortality from which the non-AIDS infant mortality rate is determined. For example, the ratio of the AIDS under-five mortality rate obtained from Spectrum to the all-cause under-five mortality rate using estimates of IGME for Botswana and South Africa ranges from 48% - 62% and 47% - 57% between 2004 and 2007, whereas the corresponding ratios for infant mortality rate are between 9% - 18% and 8% - 19% for Botswana and South Africa respectively during the same period. Therefore the non-AIDS infant mortality rates computed from the non-AIDS under-five mortality rates are too low, which in turn underestimates the all-cause infant mortality rates.

4.3.3.1 Assessment of the appropriateness of the West model life table for Botswana

The IGME employ interpolation to determine the non-AIDS infant mortality from the non-AIDS under-five mortality using the West model life table for Botswana. Figure 4.17 shows the plot of the ratio of the infant mortality to the under-five mortality compared with that computed from the West model life table, estimates from projection models excluding HIV/AIDS and empirical estimates corresponding to the period of no or low HIV/AIDS. The ratios computed from the estimates of the ASSA2003 model, DHS1988 and USCB are on average lower by 7 per cent (when the under-five mortality rate is between 49 and 80 per 1000) as compared to those computed from the West model life table. The infant mortality rates are determined from the under-five mortality rates using the West and the North model life table (the North model life table is close to the pattern revealed by the DHS 1988, ASSA2003 and USCB estimates); the infant mortality rates determined using the West model life table are higher by 7% - 11% as compared to those determined using the North model life table when the under-five mortality rate is greater than 49. When the under-five mortality rate is less than 49 the ratio of the infant mortality rate to the under-five mortality rate computed from the North and West model are close and the values of the infant mortality rates determined from the under-five mortality rates using these models become virtually the same. Therefore the non-AIDS infant mortality rates interpolated from the non-AIDS under-five mortality rates which are greater than 49 per 1000, using the West model life table appear to be slightly high. Thus, the all-cause infant mortality rate produced by the IGME for Botswana could be exaggerated as a result of the choice of the West model life table.

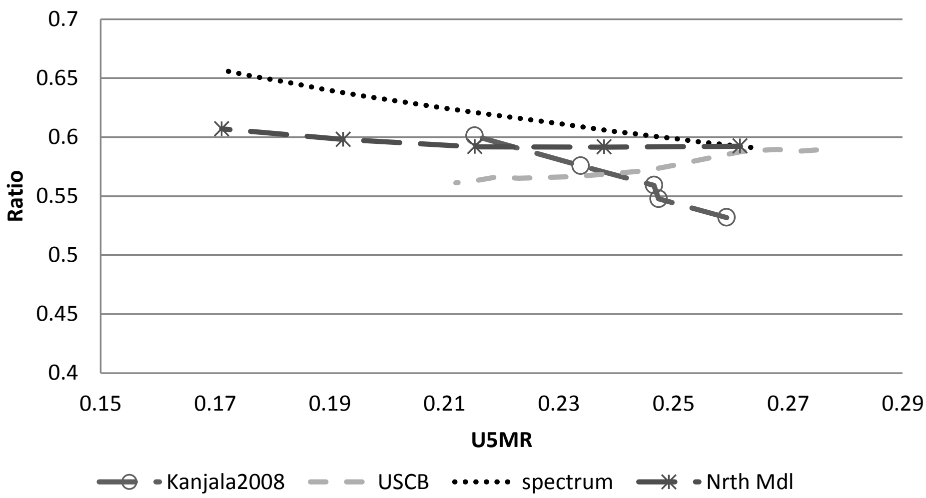
Figure 4.17 Plot of the ratio of IMRs to U5MRs: Botswana



4.3.3.2 Appropriateness of the North model life for Malawi

Interpolation is applied by the IGME to determine the non-AIDS infant mortality of Malawi from the non-AIDS under-five mortality using the North model life table. The plot of the ratios of the infant mortality rates to under-five mortality rates against the under-five mortality rates of Malawi using the non-AIDS estimates of Spectrum, the USCB estimates corresponding to the period of no or low HIV epidemic, estimates determined by Kanjala (2008) from DHS data before the time of high HIV epidemic and the North model life tables are presented in Figure 4.18. Referring to this figure, the ratios of the infant mortality rates to the under-five mortality rates computed from the North model life tables lie in between and do not deviate significantly from the ratios computed from Spectrum although it assumes the South model and those determined from the USCB and Kanjala (2008). Thus the use of the North model life table probably does not have a big effect on the non-AIDS infant mortality and hence the infant mortality rates produced by the IGME for Malawi.

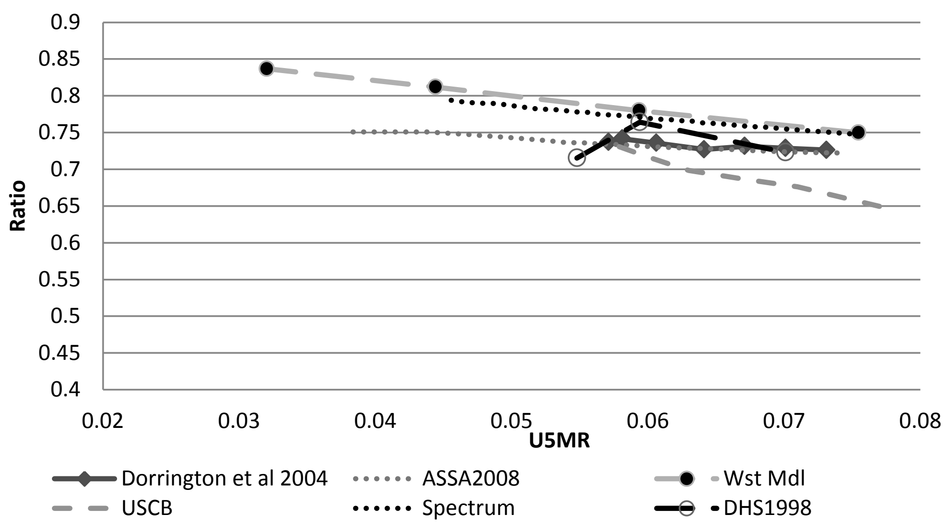
Figure 4.18 The ratio of IMR to U5MR: Malawi



4.3.3.3 Assessment of the suitability of the West model life table for South Africa

Figure 4.19 compares the ratios of the infant mortality rates to the under-five mortality rates computed from empirical results corresponding to the period of low or no HIV epidemic and the non-AIDS estimates determined from projection models with those of the ratios computed from the West model life tables. According to this comparison, the ratios of the infant mortality rates to the under-five mortality rates computed from the West model life tables are not significantly different from those of the ratios computed from projection models and empirical results. Therefore the IGME infant mortality rates for South Africa especially those of the non-AIDS infant mortality rates, are not particularly affected by the choice of the West model life table.

Figure 4.19 Ratio of the IMR to U5MR plotted against the U5MR using values of the West model life table and other results for South Africa



Generally, the use of the West model life table for South Africa and the North model life table for Malawi does not affect the non-AIDS infant mortality determined from the corresponding non-AIDS under-five mortality rate using techniques of intepolation, and hence the all-cause infant mortality rates produced by the IGME for these countries are not much affected by the use of those model life tables. However, the infant mortality rates of Botswana produced by the IGME appear to be inflated a little as a result of the use of the West model life table, especially when the non-AIDS under-five mortality rate is greater than 49.

According to the empirical and logical assessments and the results of Blacker and Brass model, the South African infant mortality rates determined by the IGME appear to be consistent with the estimates produced by othes over the period of observation. The infant mortality rates determined by the IGME for Botswana between 1980 and 1995 and after 2002 are consistent with other empirical results. However, those estimates corresponding to the period between 1996 and 2002 appear to be inflated. Similarly, the Malawian IGME infant mortality rates corresponding to the period between 1992 and 1998 and after 2006 appear to be low; otherwise, the estimates are consistent with other empirical results.

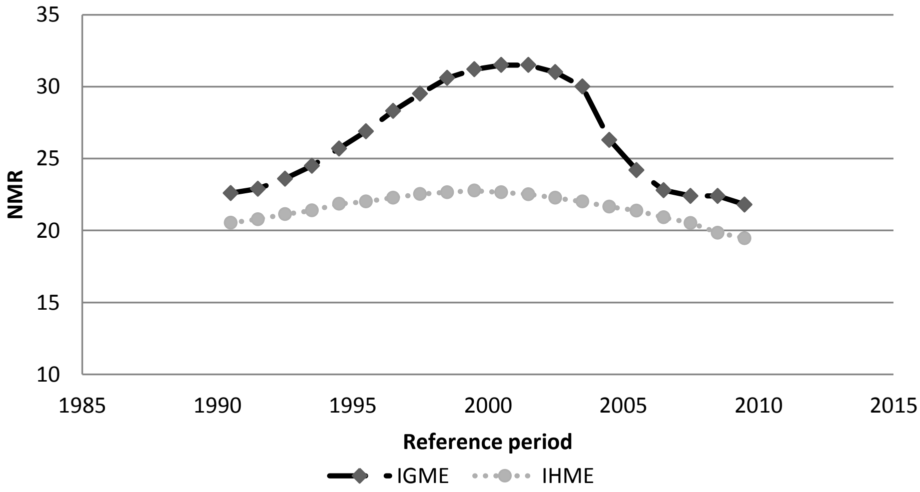
4.4 Assessment of the neonatal mortality rate

4.4.1 Empirical assessment of the neonatal mortality rate

4.4.1.1 Empirical assessment of the neonatal mortality rates for Botswana

Figure 4.20 compares the neonatal mortality rates computed by the IGME and the IHME for Botswana between 1990 and 2009. The IGME estimates are higher than the estimates computed by the IHME over the period of observation. However, the difference between the IGME and the IHME estimates is not material in the first five and last five years of the period of observation. During the period (1995 to 2004) of high HIV/AIDS epidemic with no or limited use of ART the IGME neonatal mortality rates rises quickly (from a value of 26 to 31, shown in Table B 3, Appendix B) while the IHME results remain fairly stable at a value of about 22, and the discrepancy between the IGME and the IHME neonatal mortality rates becomes significant.

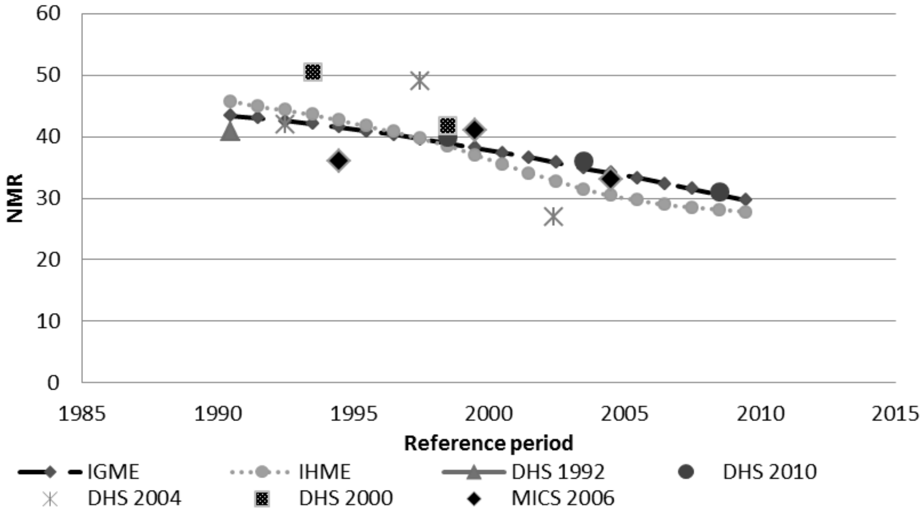
Figure 4.20 The neonatal mortality rates determined by IGME and IHME for Botswana



4.4.1.2 Empirical assessment of the neonatal mortality rates of Malawi

Figure 4.21 presents the neonatal mortality rates produced by the IGME, the IHME, MICS 2006 and those obtained from DHSs conducted between 1992 and 2010 for Malawi. The neonatal mortality rates estimated by the IGME are very close to the estimates of the IHME, although the IGME estimates are higher by 10-12 per cent between 2002 and 2007. In addition, the IGME neonatal mortality rates are more or less consistent with the estimates obtained from MICS 2006 and DHSs reports especially after 1994 although the neonatal mortality rates computed from the 2004 DHS data referring to periods 0-4 and 5-9 years before the surveys date. This is because those estimates (computed from the 2004 DHS data) referring to periods 0-4 and 5-9 years before the surveys data are widely considered to be underestimated and overestimated, respectively due to misclassification of year of death (Zimba, Kinney, Kachale *et al.* 2012). Thus taking this into account, the neonatal mortality rates of Malawi computed by the IGME appear to be consistent with other empirical results.

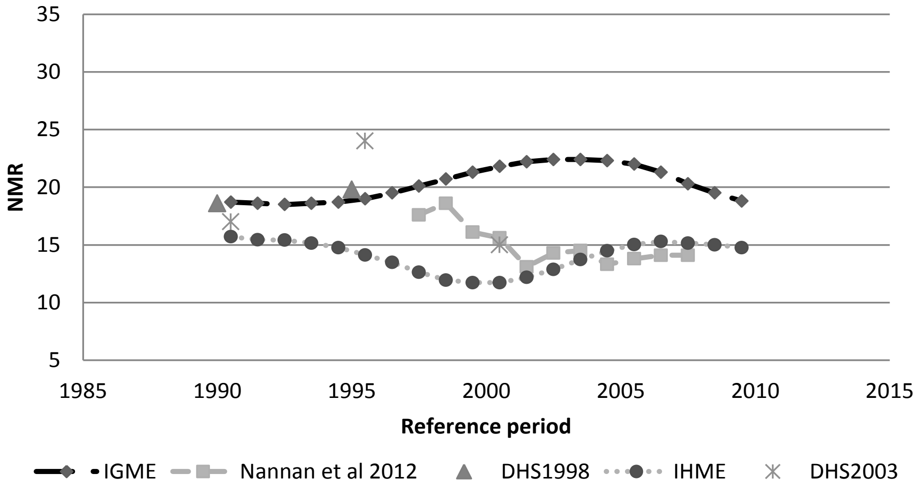
Figure 4.21 The neonatal mortality rates determined by the IGME, IHME and DHS



4.4.1.3 Empirical assessment of the South African neonatal mortality rates

The South African neonatal mortality rates produced by the IGME are not significantly different from those computed from the 1998 SADHS and vital statistics data corrected for the level of incompleteness unlike the results of IHME between 1990 and 1998, presented in Figure 4.22. Between 1998 and 2004, the IGME neonatal mortality rates rise slightly from a value of 20 to 22, shown in Table B 3, Appendix B (like the under-five mortality rates) whereas those computed from the 2003 DHS and vital statistics data decline from 18 to a value of about 14 (which is unlikely to be due to error in the vital statistics data since the quality of the data are getting better with time (Nannan, Dorrington, Laubsher *et al.* 2012)), which is an indication of a problem in the IGME results in this period. After that, the IGME results decline while the results from the vital statistics data and IHME (after 2004) remain stable and the discrepancy from these results remains significant.

Figure 4.22 Plot of the IGME NMRs and those obtained from other sources



Generally, the IGME neonatal mortality rates of Botswana and South Africa rise and follow the pattern of the under-five mortality rates during the period of high mortality of children due to HIV/AIDS. However, most studies suggest that there is no significant association between the mortality of infants during the neonatal period and the HIV/AIDS epidemic (Bloland, Wirima, Steketee *et al.* 1995; Bourne, Thompson, Brody *et al.* 2009; Brocklehurst and French 1998; Kennedy and Fawcus 2012; Kim, Mwiya, Kankasa *et al.* 2011; Rollins, Little, Mzolo *et al.* 2007). Thus the increase in the value of the IGME neonatal mortality rates following the epidemic of HIV/AIDS could be due to the estimation of neonatal mortality rates from under-five mortality rates using the model that relates neonatal mortality rates and under-five mortality rates. Therefore, the IGME estimates in these countries are too high and are inconsistent with the estimates produced by others during the period of high HIV/AIDS epidemic. However, since the IGME under-five mortality rate of Malawi is almost the same as the under-five mortality rate not corrected for the bias due to HIV/AIDS, the IGME neonatal mortality rate determined from it is consistent with the empirical estimates determined by others.

4.4.2 Logical assessment of the neonatal mortality rate

The causes of death of children under the age of five years are broadly categorised as being due to endogenous or exogenous factors (Andreev 2011; Bourgeois-Pichat 1951; McDaniel 1981; Stockwell, Swanson and Wicks 1988). The endogenous causes are related to biological or genetic factors and foetal health, whereas the exogenous causes are those mostly related to environmental or external causes such as communicable diseases, parasites and accidents (Bourgeois-Pichat 1951; Kaushik, Parmar, Grover *et al.* 1998; Moss and Carver 1998; Visaria 1985). In developed countries the causes of death of neonates are mostly due to endogenous (Andreev 2011; Karkal 1985) and the exogenous causes are the most important causes of death of children older than one month (Karkal 1985; Stiegler 2009). On the other hand in developing countries the exogenous causes are also important causes of death of children in the neonatal period with the exception of HIV/AIDS and Malaria (Lawn, Cousens and Zupan 2005; Lawn, Wilczynska-Ketende and Cousens 2006), and as mortality declines the endogenous causes become increasingly important causes of death for neonates (Andreev 2011). Similarly, studies by Bloland, Wirima, Steketee *et al.* (1995); Kazembe and Mpeketula (2010); Ticconi, Mapfumo, Dorrucci *et al.* (2003); Villamor, Msamanga, Aboud *et al.* (2005) indicate that unlike in the case of children between one month and five years, HIV/AIDS is not a major direct cause of death of children in the neonatal period. Thus one can conclude that the neonatal mortality is insensitive to or is not significantly affected by the epidemic of HIV/AIDS. The proportion of child deaths due to HIV/AIDS was between 48% to 15%, 16% to 13% and 36% to 28% between 2000 and 2010 in Botswana, Malawi and South Africa respectively (UNICEF 2012). Thus, unlike in the neonatal period, HIV/AIDS largely determines the survival of children older than one month and it is the main reason for the reversal of the downward trend in child mortality for countries affected by HIV/AIDS (Adetunji 2000; Amouzou and Hill 2004; Campbell, Kereng, Malmborg *et al.* 2012; Garenne and Gakusi 2009; Sartorius, Kahn, Vounatsou *et al.* 2010). Therefore, relating the neonatal mortality and the under-five mortality (that contains the HIV trend), doesn't make much sense, which could lead to the neonatal mortality rates produced by the IGME from the under-five mortality being inconsistent with the results produced by others, at least for countries experiencing high HIV/AIDS with low background mortality.

According to the empirical and logical assessments, the South African neonatal mortality rates determined by the IGME between 1990 and 1998, and those of Botswana between 1990 and 1994 and after 2004 are consistent with other empirical estimates. However, the estimates of South Africa in the period after 1998 and Botswana between 1995 and 2004 appear to be exaggerated and have the HIV trend. The neonatal mortality rates of Malawi computed by the IGME are consistent with the results produced by others over the period of observation and the HIV trend is not very apparent.

5 DISCUSSIONS AND CONCLUSIONS

5.1 Introduction

The main purpose of this study was to assess the methods of estimating the infant and neonatal mortality rates employed by the Inter-agency Group for Child Mortality Estimation in countries affected by HIV/AIDS using Botswana, Malawi and South Africa as a case study. In the process the study also assessed the method of estimating the under-five mortality rate since the neonatal and infant mortality rates are determined from the IGME under-five mortality rates. This chapter discusses the extent to which the research objectives have been met, what conclusions can be drawn and indicates further areas of research.

Due to the absence or incompleteness of vital registration data in developing countries, especially those in sub-Saharan Africa, countries in the region depend on survey data for the measurement of mortality below the age of five years. The level and trend of mortality rates below the age of five years computed from a variety of sources may differ due to differences in the estimation methods and/or differences in the quality of the data obtained from different sources and hence cause difficulty in identifying the trend of mortality under the age of five years in these countries. Sometimes, it may not be possible to get a reliable estimate of mortality for finer age divisions since the data used for computing mortality in these are affected by errors; it may not even be possible to get the rates because some surveys do not collect the required data. Accordingly, the IGME has developed methods for estimating the level and pattern of under-five mortality using under-five mortality rates computed from different survey data and also estimates the level and pattern of neonatal mortality rate and infant mortality rate from the under-five mortality rate. Currently the estimates determined by these models are widely used for appraising the achievement of MDG4 and resulting policies. However, no study has been conducted for assessing the details of these methods and this motivates the need to conduct this study.

5.2 Assessing the IGME methods

The IGME results of Botswana, Malawi and South Africa were compared with other estimates from population projection models and empirical results to determine if the IGME results are consistent with other empirical results. Moreover, relevant literature was reviewed in order to assess the reasonableness and the impact of the assumptions made by the method, since there is no "gold standard" against which the results could be assessed.

The under-five mortality rates determined by the IGME method for the countries under study follow a similar trajectory of other empirical results, as shown by plotting their results with other empirical estimates of the countries included in the study (see Figures 4.1, 4.2 and 4.3), except the trajectory of the estimates of Botswana and South Africa, determined by Garenne and Gakusi (2009) after the peak in the under-five mortality during the period of high HIV/AIDS epidemic, and the IHME estimates of South Africa during the period of high mortality of children due to HIV/AIDS. Though the empirical results follow similar trajectories, before the HIV/AIDS epidemic the results obtained from the different sources were close. Whereas after the HIV/AIDS epidemic the disparity between the results obtained from the different sources has increased which is the result of differences in assumptions and computation methods for correcting the bias in the results due to HIV/AIDS.

A closer assessment of the IGME method for estimating the under-five mortality rate indicated that the method appears to produce estimates that are consistent with other estimates of under-five mortality rate for South Africa over the period of observation and for Botswana between 1980 and 1998 and after 2003; while between 1998 and 2003 the under-five mortality rates of Botswana appear to be overestimated. The PMTCT programme in Botswana was introduced in 1999 and 27%, 37%, and 89% of HIV positive women used PMTCT in 2002, 2003 and 2007, respectively (NACA 2008; UNAIDS and NACA 2010). Moreover, the ART programme of Botswana was established in 2001 and about 72% of HIV-positive children among those in need were receiving ART by about 2006. However, the method used by the IGME to produce these results assumes that ART didn't have an impact on child survival before 2007 and that HIV transmission from mother to child was not reduced because of PMTCT. The assumptions of no impact of ART before 2007 on the survival of children and PMTCT on the reduction of HIV transmission by the IGME method may have inflated the under-five mortality rates computed from the 2007 Botswana Family and Health Survey data for the period between 1998 and 2003. However, these assumptions may not have an impact on the South African IGME under-five mortality rates because the percentage of people on ART was low before 2008 and no survey data after 2003 has been used by the IGME. This could be the reason why the IGME appear to be consistent with other empirical estimates. The above discussion suggests that a generalised assumption regarding the impact of interventions on child and maternal survival should not be made among countries since the time of the introduction and the use of the interventions differ between countries. The under-five mortality rates of Malawi are consistent with empirical results produced by others before 1991, although since 1992, during periods of high HIV prevalence, the method appears to underestimate the results which could be due to the reason mentioned in section 4.1.1. Thus one can suggest that for countries having low background mortality and affected by HIV/AIDS the IGME method produces results that are consistent with other empirical estimates. However, if the percentage of people on PMTCT and ART is high before 2007 the method may produce inflated results during the period of high mortality of children due to HIV/AIDS. Therefore, those who are interested in interpreting the level and pattern of the under-five mortality in these countries using estimates of the IGME should consider the level of use of ART and PMTCT in the country. While the method appears to underestimate the under-five mortality rate of countries affected by HIV/AIDS and having high background mortality during the period of high HIV/AIDS as shown in the case of Malawi and hence the results should be rejected. However, further research should be conducted in countries affected by HIV/AIDS and having high background mortality in order to strengthen this conclusion.

Mortality rates that are wrong may lead to wrong policy decisions and planning. Inflated under-five mortality may lead to, for example, misinterpretation of the impact of those interventions implemented for improving child survival, or to underestimation of a school age population in the future and hence results in wrong planning such as the construction of less number of schools, training too few teachers and printing too few text books. In addition reduction of child mortality may be given a higher priority and hence more health facilities may be established, resources may be invested on child immunization and improvement of maternal health. The converse is true when under-five mortality is underestimated.

It was also shown that the assumptions of same under-five mortality rate for HIV-positive births regardless of whether the infection occurred perinatally or postnatally and a median survival time of 9.5 years since infection for HIV positive mothers in order to determine the mortality schedule of women, by the IGME method may overstate the under-five mortality rates. However, the impact of these assumptions on the IGME under-five mortality rates is not clearly visible in the empirical results.

This could be because the over adjustment due to the above assumptions is counteracted by other assumptions, such as similar mortality of HIV-negative births irrespective of the HIV status of the mother.

The assessment of whether to exclude the indirect under-five mortality rates by the IGME method in the modelling process during the period of high HIV/AIDS prevalence is determined by comparing the direct and the indirect under-five mortality rates. The comparison is made after correcting the direct and the indirect under-five mortality rates for the bias due to HIV/AID, using the Hill and Walker method and the Ward and Zaba method crudely adjusted to allow for changes in the prevalence of HIV over time respectively. According to this comparison, the direct and the indirect under-five mortality rates for Malawi are not significantly different and hence the exclusion of the indirect under-five mortality rates does not affect the IGME results for Malawi. The indirect under-five mortality rates of South Africa are significantly higher than the direct under-five mortality rates. However, the exclusion of the indirect under-five mortality rates by the IGME probably resulted better estimates because studies (Dorrington, Moultrie and Timaeus 2004; Nannan, Timaeus, Laubscher *et al.* 2007) indicate that the indirect method produces exaggerated results for South Africa.

The IGME infant mortality rates which are estimated from the under-five mortality rates are affected by problems in the under-five mortality rates. For example, the infant mortality rates of Botswana between 1996 and 2003 are too high, like the under-five mortality rates in the corresponding period. Similarly, the infant mortality rates of Malawi between 1992 and 1998 and after 2006 are too low because the under-five mortality rates in the corresponding periods are too low. Since there is no problem in the IGME under-five mortality rates of South Africa, the infant mortality rates computed from them appear to be consistent with the results produced by others. This suggests that the IGME method produces infant mortality rate from the under-five mortality rate that are consistent with the results produced by others if there is no problem in the under-five mortality rate. Thus one should consider the reasonableness of the under-five mortality rates before interpreting the level and pattern of the infant mortality rates obtained from the IGME.

The infant mortality rates are computed using the Blacker and Brass method from the neonatal mortality rate (after removing the HIV trend in the neonatal mortality rate) and the under-five mortality rate for Botswana and South Africa. The IGME results of South Africa and Botswana are very close to those estimates determined using the

Blacker and Brass method for the respective countries. This model is not able to indicate the problem in the IGME result of Botswana between 1996 and 2003, unlike that indicated using the empirical results, because it computes the results from the under-five mortality rate (the under-five mortality rate is high during the corresponding period). Also the ratios of infant mortality rates to under-five mortality rates computed from the West and North model life tables are close to the ratios computed from the non-AIDS empirical results of South Africa and Malawi respectively, and thus the choice of the West and North model life tables to represent the non-AIDS mortality pattern below the age of five years for South Africa and Malawi respectively, probably do not distort the infant mortality rates of South Africa and Malawi. However, the ratios of the infant mortality rates to under-five mortality rates computed from the West model life tables are higher on average by about 10% as compared to the ratios determined from the non-AIDS empirical results when the under-five mortality rates are between 49 and 80 per 1000. Thus the choice of the West model life table results in slightly higher (7% - 11%) non-AIDS infant mortality rates as compared to those determined using the North model life table, which is closer to the ratios computed from the non-AIDS empirical estimates.

The study also indicated that the assumption that no Cotrimoxazole is provided to HIV-positive children exaggerates both infant and child deaths due to HIV/AIDS. This in turn understates the non-AIDS under-five mortality, which is determined by subtracting the under-five mortality due to AIDS from the all-cause under-five mortality determined by the IGME. Therefore, the non-AIDS infant mortality estimated by the IGME from the non-AIDS under-five mortality is understated. In order to determine if the addition of the over adjusted AIDS infant mortality corrects the lower adjusted non-AIDS infant mortality and hence the IGME method produces infant mortality rates that are consistent with the results produced by others, the percentage of AIDS infant mortality to the all-cause infant mortality and the AIDS under-five mortality to the all-cause under-five mortality were compared. According to this comparison, the percentage of AIDS under-five mortality to the all-cause under-five mortality is between 47% and 62%, whereas the percentage of AIDS infant mortality to the all-cause infant mortality is between 8% and 19% during the period 2004 to 2007 for Botswana and South Africa. Thus the assumption of no Cotrimoxazole is provided to HIV-positive children understate the IGME infant mortality rates. Therefore, the IGME should get the number or percentage of children using Cotrimoxazole in each country affected by

HIV/AIDS, and considers its impact on the estimation of deaths of children due to HIV/AIDS.

The IGME method produces neonatal mortality rates that have the HIV trend and are higher than the true rates for countries having low background mortality and affected by the HIV/AIDS epidemic, as indicted in the case of Botswana and South Africa. Before the period of the HIV/AIDS epidemic the method appears to produce results that are consistent with other independent empirical estimates. The proportion of child mortality due to AIDS reduced at a relatively faster rate in Botswana (from 48% to 16% between 2000 and 2010) than in South Africa (from 36% to 28% over the same period) (UNICEF 2012). This could be the reason why the IGME neonatal mortality rates of Botswana are consistent with other empirical results, while those of South Africa are not, during the period of declining AIDS-specific child mortality, after the early 2000s. As indicated by studies (Bloland, Wirima, Steketee *et al.* 1995; Bourne, Thompson, Brody *et al.* 2009; Kennedy and Fawcus 2012; Nannan, Dorrington, Laubsher *et al.* 2012) HIV/AIDS is not a direct major cause of children in the neonatal period. Therefore, the increase in under-five mortality following the HIV/AIDS epidemic in countries affected by HIV/AIDS is because of deaths of children older than one month due to HIV/AIDS. Thus the IGME method for estimating the neonatal mortality rate, tries to relate deaths which have some unrelated causes. This could be the reason why the IGME neonatal mortality rates of Botswana and South Africa are higher and have the HIV trend during the period of high HIV/AIDS prevalence. The IGME neonatal mortality rates for Malawi, also determined from the under-five mortality rates, are not significantly different from other empirical estimates of the neonatal mortality rate and the impact of HIV/AIDS is not very apparent in the estimates, and hence the IGME neonatal mortality rates appear to be consistent with estimates produced by others. This could be because the under-five mortality rates of Malawi determined by the IGME model are virtually the same as those not corrected for the bias due to HIV/AIDS, or due to lower level of adult HIV prevalence in the country and hence lower proportion of child deaths due to HIV/AIDS (for example, the proportion was between 13% in 2010 and 16% in 2000 (UNICEF 2012). Therefore, the results can be used for designing programmes and formulating policies that focus on the survival of neonates. Though the IGME neonatal mortality rates of Malawi are consistent with other results at the moment; the method may not produce neonatal mortality rate that are consistent with other empirical results if the problem in the

IGME under-five mortality rate of Malawi during the period of high HIV/AIDS is adjusted. From the above discussions one can conclude that the AIDS-related mortality that exists in the under-five mortality rate should be removed before estimating the neonatal mortality rate from it for countries affected by HIV/AIDS. This is because the exogenous cause of death (such as communicable diseases, especially HIV/AIDS) of children under the age of five are high in these countries hence the estimation of the neonatal mortality rate from the under-five mortality rate may inflate the results.

5.3 Limitation of the study

The IGME methods for producing the estimates of under-five mortality, infant mortality and neonatal mortality rates are assessed using estimates from projection models and empirical results from survey and vital statistics data. However, the projection estimates have their own limitations and are largely dependent on the assumptions made in developing the models (Andreassen 1992; National Research Council 2000; Rowan and Wright 2010). The empirical results are affected by the quality of survey data, which are mostly affected by coverage, response and sampling errors. Moreover, the assumptions made by the methods used for computing empirical results from survey data and projection models are affected by the HIV/AIDS. Thus there is uncertainty around the estimates from projection models and empirical results and the uncertainty increases after the HIV/AIDS epidemic. Hence it is difficult to draw strong conclusions about the reasonableness of the IGME under-five mortality and infant mortality rates especially after the period of the HIV/AIDS epidemic.

The empirical results used for validating the neonatal mortality rates are very few. For example, for Botswana only the results of the IHME are used and for South Africa the empirical estimates of Nannan, Dorrington, Laubsher *et al.* (2012) is used to validate the IGME neonatal mortality rates between 2000 and 2006. Thus the strength of the conclusions made about the estimates of neonatal mortality for Botswana over the period of observation and that for South Africa between 2000 and 2006 is in question.

This study fails to determine the net effect of the assumption that overstate (similar mortality of HIV-positive births regardless of whether the infection occurred perinatally and postnatally and no impact of ART before 2007) and understate (similar mortality of HIV-negative births irrespective of the HIV status of the mother) the under-five mortality rate computed from full birth history data on the IGME results, and concluded that those assumptions that overstate the results could be counteracted by those understate the results.

5.4 Scope for further research

The IGME fitted a regression model to the neonatal mortality and the under-five mortality rates computed from survey and vital registration data obtained from all developing countries having incomplete or no vital registration data, regardless of the prevalence of HIV/AIDS in the country. The regression coefficients obtained from this model are used to estimate and project the pattern and level of neonatal mortality rates for all developing countries. The impact of using the same regression coefficients for all countries regardless of the HIV/AIDS epidemic is not determined in this research. Thus, further research should be conducted in order to ascertain the impact of using the same regression coefficients on the resulting neonatal mortality rates by fitting different regression models for countries affected by HIV/AIDS and those not affected by HIV/AIDS.

This study assesses the validity of the IGME methods, especially for those countries affected by the HIV/AIDS epidemic and may not be applicable to the IGME methods in countries not affected by the epidemic. Thus it is important to conduct a similar study to assess the validity of the IGME methods in these countries.

The HIV prevalence rate in Malawi was above 9.5 in 1992. However, the infant mortality rates of Malawi determined by the IGME between 1992 and 1998 and after 2006 are virtually the same as the infant mortality rates not corrected for the bias due to HIV/AIDS. Thus this study argues that the IGME infant mortality rates appear to be underestimated. In order to quantify the deviation of the IGME results from the infant mortality rates computed from full birth history data corrected for the bias due to HIV/AIDS, first the under-five mortality rates are determined using the Hill and Walker method, and then the infant mortality rates are interpolated from the resulting under-five mortality rates using the Coale and Demeny model life table. The reason for doing all these steps is that the Hill and Walker method corrects only the bias due to HIV/AIDS in the under-five mortality rates. This method therefore has to be extended to estimate the infant mortality rates corrected for the bias due to HIV/AIDS.

The assumptions of same mortality for HIV-positive births regardless of whether the infection occurred perinatally or postnatally and a median survival time of 9.5 years since infection for HIV positive mothers in order to determine the mortality schedule of women by the IGME method may overstate the IGME under-five mortality rate. Similarly, the assumption of same mortality of HIV-negative births regardless of the HIV status of the mothers by the IGME method may understate the IGME under-five mortality rates. This study concludes that the combined effect of these assumptions on the IGME under-five mortality rates cancel out to some extent. However, the extent of the cancellation is uncertain. Thus, further research should be conducted to quantify the impact of these assumptions as well as the net effect on the resulting IGME estimates.

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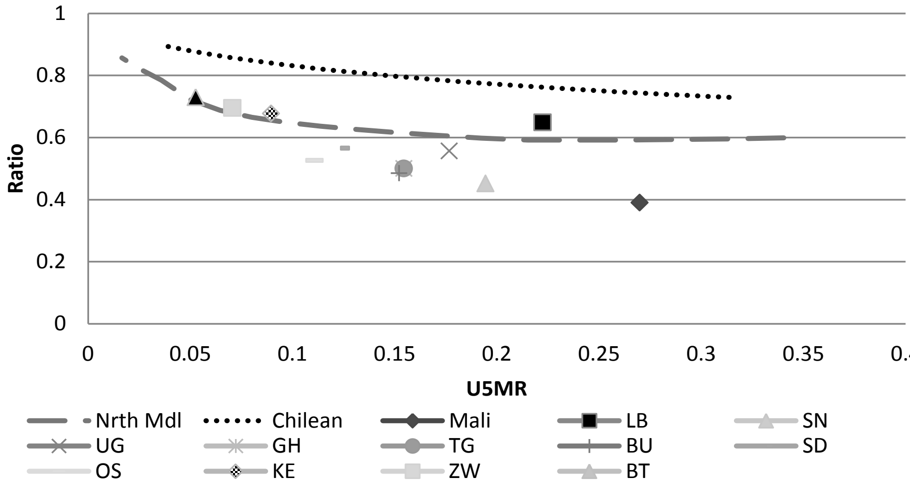
APPENDIX

APPENDIX A: The pattern of mortality below five years of age in developing countries relative to the pattern in common model life tables

The ratios of infant to under-five mortality computed using data from fourteen countries in the Near East, North Africa, Asia, Latin America and the Caribbean, lie between those of the North (highest ratios) and the Chilean (lowest ratios) model life tables (figure not included) (Sullivan, Rutstein and Bicego 1994). Figure A 1 shows the plot of the ratios of infant to under-five mortality computed from DHS data collected between 1985 and 1990 in twelve Sub-Saharan countries compared to the North and Chilean model life tables. Only the ratios from countries having a low level of mortality during the time of the survey, such as Botswana, Kenya and Zimbabwe, lie within the plot of the North and Chilean model life tables. The ratios for the remaining countries except Liberia, having high mortality lie below the plot of the North model life table. Thus in high mortality countries of Sub-Saharan Africa there is a relatively higher concentration of deaths between ages one and five years as compared to countries in the developing region (Sullivan, Rutstein and Bicego 1994) and other developing countries. In addition, in sub-Saharan countries a high level of mortality extends to the age range between two and five years instead of being limited between age zero and two years. The above facts are, therefore, evidence that the mortality experience of sub-Saharan population below the age of five years is not represented by the Coale and Demeny and UN-regional model life tables (Sullivan, Rutstein and Bicego 1994).

Figure A 1 The ratio of IMR to U5MR against the U5MR computed from the North and Chilean model life tables and DHSs between 1985 and 1990



BT(Botswana), BU(Burundi), GH(Ghana),KE(Kenya), LB(Liberia), ML(Malai), OS(Ondo State Nigeria), SD(North Sudan), SN(Senegal), TG(Togo), UG(Uganda), ZW(Zibabwe)

Source:Sullivan, Rutstein and Bicego (1994)

Appendix B Under-five, infant and neonatal mortality rates obtained from various sources for the countries studied

Table B 1 Under-five mortality rates for Botswana, Malawi and South Africa obtained from various sources

	Botswana					Malawi							
year	IGME	spectrum	IHME	ASSA	Garenne &Gakusi	IGME	Spectrum	USCB	IHME	Garenne &Gakusi	DHS 2010	year	Kanjala 2008
1980.5	80.8	93.55		85.10	65.82	254.4	263.5	275		282.39		1980.3	259.3
1981.5	76.8	90.05		81.71	62.79	248.2	258.9	272		274.80		1982.4	215.3
1982.5	72.9	86.65		78.46	59.90	243.7	254.4	268		267.33		1983.2	251.8
1983.5	69.3	83.35		75.36	57.13	240.6	250.4	262		260.00		1985.3	246.6
1984.5	65.9	80.1		72.41	54.48	238.4	247	256		250.09		1987.4	214.6
1985.5	63	77		69.66	51.94	236.4	243.7	250		246.92		1988.2	247.4
1986.5	60.8	74.1		67.20	49.52	234.8	240.6	245		243.78		1990.3	233.8
1987.5	58.9	71.4		65.15	47.21	232.2	237.6	239		240.67		1992.4	189.7
1988.5	57.5	68.9		63.73	49.85	230	232.7	233		237.58		1993.2	219.6
1989.5	57.5	66.65		63.27	52.64	226	226.2	228		234.52		1997.4	186.8
1990.5	58.7	64.75	55.2	64.08	55.57	222.1	220.6	223	209.8	231.49		1998.2	188.6
1991.5	60.6	63.25	56.4	66.51	58.65	218.1	215.4	219	205.8	228.49		2002.4	133.4
1992.5	63.2	62.75	57.8	70.82	61.90	214.7	210.4	215	201.6	225.92			
1993.5	66.6	63.8	59.2	76.78	65.31	212.5	205.8	212	197.2	216.27			
1994.5	70.9	65.95	60.7	83.64	68.90	209.3	201.4	209	192.3	206.93			
1995.5	76.1	68.75	62.1	90.49	72.66	205.1	197.2	206	187	197.88			
1996.5	81.7	72.05	63.5	96.55	76.62	199.4	193.1	203	181	189.14			
1997.5	87.2	75.6	64.6	101.38	80.77	191.1	188.7	200	174.4	180.70	180		
1998.5	91.9	79.1	65.3	104.86	85.13	182.6	184.5	197	166.8	172.55			
1999.5	94.9	81.65	65.5	106.55	89.70	174.5	180.6	193	158.4	164.70			
2000.5	95.9	82.75	65.1	104.18	94.49	166.5	176.2	190	149.5	157.14			
2001.5	95.4	83	64.4	97.27	99.50	158.7	171.4	186	140.6	149.86			
2002.5	93.1	82.25	63.3	87.20	104.76	150.9	166.5	182	132.3	142.86	145		
2003.5	87.9	81.15	62.1	74.58	110.25	143.4	161.7	178	125	136.14			
2004.5	70.4	80.85	60.6	63.46	116.00	135.7	156.8	174	119	129.68			
2005.5	60.9	78.95	59	59.20	122.01	128.1	151.8	170	114.3	123.49			
2006.5	54.9	72.25	57.2	58.70		120.4	146.2	165	110.7				
2007.5	52.4	64.8	55.1	58.30		112.4	139.9	160	107.9		112		
2008.5	51.8	60.95	52.9	57.72		104.7	134.4	156	105.6				
2009.5	49.4	58.8	50.7	56.69		98.1	130.6	152	103.6				
2010.5	47.7	54.95	48.6	55.50		92.1	127.1	147	101.8				

Continued…

	South Africa								
Year	IGME	spectrum	IHME	USCB	ASSA	Darkwa 2010	Garenne& Gakusi	Nannan et al 2012	Dorringotn et al 2004
1980.5	89.2	90					97.84771	63.9	
1981.5	85.5	86.8					92.39594	73.4	
1982.5	81.9	83.7					87.21855	72.5	
1983.5	78.5	80.9					82.30497	72.5	
1984.5	75.3	78.3					77.64466	72.9	
1985.5	72.2	75.7		97	73.90097		73.22716	74.4	
1986.5	69.3	73.1		89	72.37952		69.04219	76.1	73.13
1987.5	66.5	70.5		83	70.85199		65.07959	75.4	70.13
1988.5	64	68.6		77	69.38493		61.32944	74.6	67.13
1989.5	61.8	67.6		71	67.7829		57.78203	75	64.13
1990.5	59.8	66.7	60.3	67	66.27417		54.42791	71.8	60.64
1991.5	58.3	65.9	58.9	63	64.7301		51.2579		58.13
1992.5	57.6	65.2	57.8	60	62.8701		48.2631		57.13
1993.5	57.9	65.3	56.4	57	61.63142		46.87591		58.64
1994.5	58.9	66.2	53.9	57	61.76642		49.48331		62.13
1995.5	60.9	67.7	50	57	62.28236		51.82826		66.13
1996.5	63.7	69.7	45.2	58	63.3033	66.1	54.27799		70.13
1997.5	67.2	72.2	40.3	60	65.23685	64.5	56.83656		
1998.5	71	74.4	36.9	63	67.34528	73.3	59.50816		
1999.5	74.7	76.2	35.7	65	69.73015	71.6	62.29703		
2000.5	77.9	77.8	36.1	67	71.8423	69.8	65.20755		
2001.5	80.5	79	38.1	68	73.3803	68.5	68.24415		
2002.5	81.6	80.1	42	69	74.32213	71.5	71.41136		
2003.5	82	81.2	46.8	70	74.0252	73.2	74.71376		
2004.5	81.4	80	51.6	70	72.52127	74.2	78.15604		
2005.5	79.9	77	55.7	69	68.98442	74.8	81.7429		
2006.5	75.8	76	57.3	68	64.91803	73.1	85.47911		
2007.5	70.3	76.1	56.5	68	61.46923		89.36947		
2008.5	65.6	73.7	55.3	67	55.13362				
2009.5	60.9	69.6	53.9	66	50.23082				
2010.5	56.6	66.1	52.3	65	49.03379				

Table B 2 Infant mortality rates for Botswana, Malawi and South Africa obtained from various sources

	Botswana					Malawi						
Year	IGME	IHME	USCB	Spectrum	ASSA 2003	IGME	IHME	USCB	Spectrum	Year	DHS 2010	Kanjala 2008
1980.5	60			69.2	58.74	150.6		162	155.8	1980.3		137.9
1981.5	57.4		61	67	56.35	146.9		160	153.8	1983.2		129.4
1982.5	54.9		58	64.8	54.05	144.2		158	151.7	1982.4		117.3
1983.5	52.6		56	62.6	51.87	142.3		154	149.9	1985.4		137.9
1984.5	50.5		53	60.6	49.80	141		149	148.4	1987.4		104.4
1985.5	48.6		50	58.5	47.89	139.8		144	147	1988.2		135.5
1986.5	47.2		48	56.5	46.18	138.9		140	145.6	1990.3		134.6
1987.5	45.9		46	54.7	44.80	137.3		136	144.3	1993.2		122.7
1988.5	44.9		43	53	43.91	135.8		132	142.2	1997.4		112.5
1989.5	44.9		41	51.4	43.70	133.2		129	139.3	1998.2		103.8
1990.5	45.6	41.59	39	50	44.39	130.9	114.72	126	136.8	2002.4		76.1
1991.5	46.8	42.42	37	48.8	46.13	128.5	112.82	124	134.3			
1992.5	48.4	43.35	36	47.8	49.06	126.5	110.91	121	132			
1993.5	50.4	44.19	35	47.8	52.80	125	108.89	119	129.8			
1994.5	52.9	45.23	35	48.7	56.63	123.1	106.63	117	127.8			
1995.5	55.8	46.07	35	49.9	59.95	120.5	104.13	114	125.7			
1996.5	58.7	46.92	35	51.3	62.41	117.2	101.38	112	123.6			
1997.5	61.3	47.65	34	52.8	63.98	112.5	98.3	110	121.3		92	
1998.5	63.4	48.07	34	54.2	64.79	107.8	94.84	108	119.1			
1999.5	64	48.27	33	55.4	64.46	103.2	90.85	106	117			
2000.5	63.9	47.96	32	55.7	61.80	98.7	86.76	104	114.7			
2001.5	63.1	47.54	31	55.8	56.37	94.4	82.52	102	112.3			
2002.5	61.1	46.81	29	55.1	49.25	90.1	78.48	100	109.8		81	
2003.5	57.8	46.07	28	53.9	41.56	85.9	74.86	98	107.3			
2004.5	45.8	45.03	27	54	34.45	81.6	71.75	96	104.9			
2005.5	43	44.09	22	53.6	30.78	77.4	69.35	94	102.3			
2006.5	40	42.84	16	49.4	29.40	73.2	67.43	92	99.1			
2007.5	39.4	41.49	14	42.9	28.26	68.9	65.96	90	95.7		66	
2008.5	39	39.94	13	42.4	27.42	64.6	64.73	88	93.1			
2009.5	37.1	38.49	13	41.3	26.63	61.4	63.71	86	91.5			
2010.5	36.1	37.04	12	40.2	25.86	58.1	62.72	84	89.7			

Continued…

	South Africa							
Year	IGME	IHME	ASSA 2008	Spectrum	USCB	Darkiwa	Nannan et al 2012	Dorrington et al 2004
1980.5	65.3			65.7				
1981.5	63			63.8				
1982.5	60.7			61.8				
1983.5	58.5			59.9				
1984.5	56.4			58.2				
1985.5	54.5		53.37	56.6	56			
1986.5	52.6		52.30	54.9	54			
1987.5	50.9		51.26	53.2	52			53.10
1988.5	49.3		50.27	52	50			51.10
1989.5	47.8		49.19	51.3	48			49.10
1990.5	46.6	43.85	48.19	50.7	46			46.61
1991.5	45.5	42.92	47.18	50.1	44			44.61
1992.5	44.9	42.29	45.92	49.6	43			43.10
1993.5	45	41.35	45.14	49.6	42			42.10
1994.5	45.5	39.78	45.36	50.2	42			43.10
1995.5	46.6	37.19	45.74	51	42			45.61
1996.5	48	33.99	46.36	52.1	43	48.4		48.10
1997.5	49.8	30.51	47.45	53.4	45	47.5	46.6	51.10
1998.5	51.5	27.96	48.34	54.4	46	53.2	52.7	
1999.5	53	27.04	49.24	55	47	51	51.1	
2000.5	54.3	27.35	49.74	55.3	48	48	49.9	
2001.5	55.1	28.87	49.69	55.6	48	45.2	49	
2002.5	54.9	31.74	49.22	55.7	48	46.6	50.1	
2003.5	54.8	35.13	47.99	55.6	48	46.6	51.2	
2004.5	54	38.33	46.50	53.7	48	45.8	49	
2005.5	52.9	40.93	44.17	52	47	48.2	49.5	
2006.5	49.2	41.97	41.32	52.6	46	47.8	50	
2007.5	47.3	41.45	39.36	52.6	46		48.6	
2008.5	45	40.72	36.35	50.9	45			
2009.5	42.5	39.78	33.00	48.4	44			
2010.5	40.7	38.75	32.40	46.6	44			

Table B 3 Neonatal mortality rate for Botswana, Malawi and South Africa obtained from various sources

	Botswana		Malawi						South Africa				
Year	IGME	IHME	IGME	IHME	DHS 2010	MICS 2006	DHS 2004	DHS 200	IGME	IHME	Nannan et al 2012	DHS 2003	DHS 1998
1990.5	22.6	20.5	43.4	45.7					18.7	15.7		17	18.8
1991.5	22.9	20.8	43	44.9					18.6	15.4			
1992.5	23.6	21.1	42.6	44.3			27		18.5	15.4			
1993.5	24.5	21.4	42.1	43.6				50.4	18.6	15.2			
1994.5	25.7	21.9	41.5	42.7		36			18.7	14.8			
1995.5	26.9	22.0	40.9	41.8					19	14.1		24	19.8
1996.5	28.3	22.3	40.3	40.8					19.5	13.5			
1997.5	29.5	22.5	39.6	39.7			49		20.1	12.6	17.6		
1998.5	30.6	22.7	38.9	38.5	40			50.4	20.7	12.0	18.6		1995
1999.5	31.2	22.8	38.2	37.0		41			21.3	11.7	16.1		1990
2000.5	31.5	22.7	37.4	35.5					21.8	11.7	15.6	15	
2001.5	31.5	22.5	36.6	34.0					22.2	12.2	13.1		
2002.5	31	22.3	35.8	32.7					22.4	12.9	14.3		
2003.5	30	22.0	34.9	31.5	36				22.4	13.7	14.5		
2004.5	26.3	21.7	34.1	30.4		33			22.3	14.5	13.3		
2005.5	24.2	21.4	33.3	29.7					22	15.0	13.8		
2006.5	22.8	20.9	32.4	29.0					21.3	15.3	14.1		
2007.5	22.4	20.5	31.5	28.5					20.3	15.2	14.1		
2008.5	22.4	19.8	30.5	28.1	31				19.5	15.0			
2009.5	21.8	19.5	29.7	27.7					18.8	14.8			