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I. BACKGROUND

The development of reliable and affordable methods for measuring adult mortality in countries that lack adequate vital statistics systems has proved a major challenge. While considerable ingenuity has been deployed to good effect to devise ways of rendering incomplete reports of recent deaths usable, such methods can only be applied when the majority of events are reported.[1] Thus, indirect techniques, of which the orphanhood method is perhaps the most widely applied and successful for the measurement of adult mortality, remain important sources of mortality estimates.

Like the statistics generated by other approaches to the measurement of adult mortality in developing countries, orphanhood estimates suffer from distinctive limitations.[2] Inherently, they measure only the overall level and trend in mortality and cannot detect unusual age patterns or short-term fluctuations in mortality. For many purposes this does not matter. More seriously, in a number of applications in East Africa and elsewhere, the orphanhood method has yielded results that indicate implausibly rapid declines in mortality and gross inconsistencies between the estimates from successive enquiries. This appears to be due to 'the adoption effect'; that is underreporting of orphanhood among those whose parents die when they are very young.[3] While the orphanhood method has performed much better in applications in

* This paper is based on sections of the author's unpublished PhD thesis presented to the University of London, 'Advances in the Measurement of Adult Mortality from Data on Orphanhood'. Most of the thesis was written at the University of Pennsylvania while on an eight-month fellowship awarded by The Population Council. Without their financial assistance and the excellent research facilities provided by the Population Studies Center, it would probably never have been completed.

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[1] See, for example, W. Brass, *Methods for Estimating Fertility and Mortality from Limited and Defective Data* (Poplab, Chapel Hill, 1975) and S. H. Preston, A. J. Coale, J. Trussell and M. Weinstein, 'Estimating the completeness of reporting of adult deaths in populations that are approximately stable', *Population Index*, **46** (1980), pp. 179–202. Developments in this field are reviewed by S. H. Preston in 'Use of direct and indirect techniques for estimating the completeness of death registration systems', in *Data Bases for Mortality Measurement* (United Nations, New York, 1984) and, more recently, by I. Timæus and W. Graham in *Measuring Adult Mortality in Developing Countries: A Review and Assessment of Methods*, Planning, Policy and Research Working Papers, WPS 155 (The World Bank, Washington, DC, 1989).

[2] See Timæus and Graham, *op. cit.* in fn. 1.

[3] See J. G. C. Blacker, 'Experience in the use of special mortality questions in multi-purpose surveys: the single-round approach' (United Nations, *op. cit.* in fn. 1). K. Hill, 'An evaluation of indirect methods for estimating mortality', in J. Vallin, J. H. Pollard and L. Heligman (eds), *Methodologies for the Collection and Analysis of Mortality Data* (Liège, 1984). I. Timæus, 'An assessment of methods for estimating adult mortality from two sets of data on maternal orphanhood', *Demography*, **23** (1986), pp. 435–450. J. G. C. Blacker and J. Mukiza-Gapere, 'The indirect measurement of adult mortality in Africa', in *African Population Conference, Dakar, 1988* (IUSSP, Liège, 1988). I. Timæus, Estimation of mortality from orphanhood in adulthood *Demography* **28** (2), 1991.

other regions,[4] such findings have thrown its validity into doubt. The reservations of some demographers about the method, combined with the scepticism that naturally exists about a method whose theoretical basis is difficult to grasp without a good training in demography, have had a major impact on those responsible for collecting demographic data.[5] This is unfortunate. The orphanhood method is no panacea, but it is premature to consign it to the waste bin reserved for good ideas that did not work.

In this paper, new techniques are proposed for estimating adult mortality from orphanhood that can be used when supplementary questions are asked in a single survey about the timing of the deaths of parents relative to first marriage. Two aims underlie the development of these methods. The first is to produce methods with a more specific time-reference than those yielded by the original method. In particular, the value of the orphanhood estimates would be greatly enhanced if they could be made for more recent dates than is possible by the basic method. Secondly, the aim is to develop methods that are less subject to bias due to the underreporting of orphanhood at young ages.

Chackiel and Orellana have proposed supplementary questions about orphanhood on the dates of death of each parent who has died.[6] These data allow one to construct synthetic cohort estimates of parental survival. Like those discussed here, these questions potentially make it possible to obtain recent and accurately dated estimates of adult mortality from data on parental survival. Moreover, methods of analysis that use only the synthetic cohort data on young adults can reduce the impact of the adoption effect on the results.[7] The major problem with Chackiel and Orellana's approach is that respondents may not be able to report the dates of death of their parents with sufficient accuracy for the information collected to be of much value. Initial trials of the method in Bolivia, Costa Rica, and Honduras yielded promising results.[8] So far, however, experience with this question is limited. In particular, it is unclear whether the approach will prove useful for estimation of adult mortality in poorly educated populations, such as those of many sub-Saharan African countries.

Information that is of potential value as a way of obtaining recent and more accurate measures of adult mortality from information on orphanhood has also been collected by the Demographic and Health Surveys (DHS) programme. The core questionnaire contains questions that establish whether parents and parents-in-law, who have died, were still alive at the time of the respondent's first marriage.[9] In an unpublished note,[10] Brass has pointed out that this supplementary information on the timing of orphanhood could be used to study adult mortality. Marriage is an event that distinguishes, for each

[4] See I. Timæus, 'Estimation of fertility and mortality from WFS household surveys', in J. Cleland and C. Scott (eds), *The World Fertility Survey: An Assessment* (Oxford, 1987). I. Timæus, 'Adult mortality: levels, trends and data sources', in R. G. Feachem and D. T. Jamison (eds), *Disease and Mortality in sub-Saharan Africa* (New York, 1990).

[5] For example, in some African countries in which the orphanhood questions were used in the 1970 round of censuses they were dropped from the census schedule a decade later. In few of these countries is information on adult mortality collected from other sources. Moreover, while questions about orphanhood were asked in a number of World Fertility Survey (WFS) studies and in most of those conducted in the first round of Demographic and Health Survey (DHS) enquiries, they have not been included in the core questionnaire for the second round of the DHS.

[6] See J. Chackiel and H. Orellana, 'Adult female mortality trends from retrospective questions about maternal orphanhood included in censuses and surveys', in *International Population Conference, Florence, 1985* (IUSSP, Liège, 1985).

[7] Timæus, *loc. cit.* in fn. 3.

[8] Chackiel and Orellana, *loc. cit.* in fn. 6.

[9] These questions were asked in 15 of the surveys conducted during the first round of the DHS programme. The main reason why the questions were included in the questionnaire was as a filter for further questions, that establish whether respondents lived with their parents(-in-law) after marriage, so that the impact of residential patterns on contraceptive use and fertility could be investigated.

[10] W. Brass, 'The estimation of adult mortality from survey reports on survivorship of relatives'.

age group of respondents, more recent parental deaths from those that occurred longer ago. While the information on the timing of deaths is less precise than that yielded by direct questions about the date of death of parents, it may be more accurately reported. Even if respondents cannot remember exactly when their parents died, it seems likely that nearly all of them will be able to report the timing of parental deaths relative to their first marriage, another event of major significance in their lives.

Brass argues that the proportion of women with living mothers at marriage is approximately equal to the life-table probability of surviving from the mean age at childbearing of women to that age plus the mean age at first marriage of the cohort of women concerned.[11] On the other hand, the proportion of mothers who have survived since female respondents married is closely related to the probability of surviving from the sum of the period mean age at childbearing and the cohort mean age at marriage until $n-\bar{m}$ years later, where n is the mean age of respondents and $\bar{m}$ the mean age at marriage of members of the cohort. Estimates made from data on orphanhood since marriage will measure more recent mortality than those based on respondents' lifetime experience of orphanhood. In addition, Brass points out, because parental deaths since marriage must have occurred when respondents were sufficiently old to remember them clearly, such data should be less subject to reporting errors than those concerning the overall level of orphanhood.

New coefficients are derived and tested here for estimating adult mortality from orphanhood before and after marriage. Although individual-level information on women's date of first marriage was collected in the DHS surveys, in future surveys in which the new questions about orphanhood are asked this question might not be put. In addition, retrospectively reported dates of first marriage are often very inaccurate.[12] Because of this, the methods developed here use aggregate information on ages at marriage to control for variation between populations in the ages of parents and the length of time that they are exposed to the risk of death. It seems unlikely that questions on the timing of deaths of parents-in-law will be included in future surveys. Moreover, in the DHS questionnaire women were not asked questions about the ages of their first husbands. Therefore, no attempt is made here to develop a procedure for analyzing these data. Finally, the coefficients developed are intended for the analysis of data supplied by female respondents. In the DHS, only women interviewed individually were asked the relevant questions and, in any case, women usually supply more reliable information than male respondents about orphanhood.[13]

II. ORPHANHOOD SINCE MARRIAGE

The derivation of the basic orphanhood method involves the assumption that the mortality of respondents is uncorrelated with the mortality and fertility of their parents.[14] To derive methods for the estimation of adult mortality from orphanhood before and after marriage, further assumptions are made that the probability that a woman marries at any age is unaffected by her parents' survival and that her age at

[11] *Ibid.*

[12] See, for example, N. Goldman, S. O. Rutstein and S. Singh, *Assessment of the Quality of Data in 41 WFS Surveys: A Comparative Approach*. WFS Comparative Studies, 44 (ISI, Voorburg, 1985).

[13] See J. G. C. Blacker 'The estimation of adult mortality in Africa from data on orphanhood', *Population Studies*, **31** (1977), pp. 107–128. G. Pison and A. Langaney, 'Age patterns of mortality in Eastern Senegal: a comparison of micro and survey approaches', in J. C. Caldwell, A. G. Hill and V. J. Hull (eds), *Micro-Approaches to Demographic Research*. (KPI, London, 1988).

[14] See W. Brass and K. Hill, 'Estimating adult mortality from orphanhood', in *International Population Conference, Liège, 1973* (IUSSP, Liège, 1973).

marriage is uncorrelated with her parents' ages at the time that she was born.[15] In addition, the mortality estimates obtained apply only to the parents of ever-married respondents. In most developing countries, nearly all women aged 25 or more fall into this category, and the results can be treated as representative of the whole population.

Given these assumptions, the proportion of women aged exactly z with living mothers, $S(z)$, depends on the probability that the mothers gave birth at any age y, ${}_zv_y$, and the probability that they survived a further z years, ${}_zp_y$:

$$S(z) = \int_s^w {}_zv_y \cdot {}_zp_y \, dy,$$

where integration is over all ages at childbearing s to w. Assuming a stable age structure ${}_z{}^vy = e^{-r(y+z)}\, l(y) f(y)\, e^{-rz}$ where $l(y)$ is the life-table survivorship and $f(y)$ the fertility rate at age y, this relationship can be evaluated numerically by summing over five-year age groups of mothers using:

$$S(z) \approx \frac{\sum_{x=s}^{w-5} e^{-r(x+2.5)}\, l(x+2.5+z) \int_x^{x+5} f(y)\, dy}{\sum_{x=s}^{w-5} e^{-r(x+2.5)}\, l(x+2.5) \int_x^{x+5} f(y)\, dy}. \tag{1}$$

If the first-marriage rate at age z is defined as $m(z)$, then the proportion of ever-married respondents aged a, whose mothers were alive at the time of the respondents' first marriage, $S^m(a)$, is:

$$S^m(a) = \int_0^a m(z) \int_s^w {}_zv_y \cdot {}_zp_y \, dy\, dz \Big/ \int_0^a m(z)\, dz. \tag{2}$$

Dividing the proportion of ever-married respondents aged a with living mothers by the proportion of respondents whose mothers were alive at their marriage, one obtains the probability that a mother has survived from the time of marriage to the time of interview:

$$\frac{S(a)}{S^m(a)} = \frac{\int_0^a m(z)\, dz \int_s^w {}_av_y \cdot {}_ap_y \, dy}{\int_0^a m(z) \int_s^w {}_zv_y \cdot {}_zp_y \, dy\, dz}.$$

The equivalent relationship, for five-year age groups of respondents, is:

$$\frac{{}_5S_x}{{}_5S^m_x} = \frac{\int_x^{x+5} \int_0^a m(z)\, dz \int_s^w {}_av_y \cdot {}_ap_y \, dy\, da}{\int_x^{x+5} \int_0^a m(z) \int_s^w {}_zv_y \cdot {}_zp_y \, dy\, dz\, da}. \tag{3}$$

Once the possibility of death between conception and birth is allowed for, Equations (2) and (3) also express the probability that a woman's father was alive when she married, and the probability, for a five-year age group, that he has remained alive since. Although the weights, ${}_av_y$, applicable to the probabilities of surviving from age y to $y+a$ differ for fathers and mothers, the marriage distribution in both cases is that of female respondents.

[15] The validity of these assumptions and the impact of breaches of them on the results is discussed in Section V.

Coefficients for the estimation of men's and women's adult mortality from orphanhood since marriage are presented in the Appendix. They have been estimated from orphanhood in a set of simulated populations, obtained from Equation (3). These data have also been used to estimate new coefficients for the basic orphanhood method.[16] The integral of ${}_av_y \cdot {}_ap_y$ was calculated from Equation (1) and the information on five-year age groups as averages of the values for exact ages x, $x+2.5$ and $x+5$, weighted by $e^{-ra}\, l(a)$.

The simulated data were created from relational logit model life tables, based on the General Standard,[17] and fertility distributions generated, using the relational Gompertz model, from Booth's standard for females and Paget's standard for males (see Table 1).[18] The age distribution of the parents is represented by a stable population with a rate of increase of two per cent. The parameters result in populations with life expectancies at birth that range from 36 to 73 years with an average of 55 years and life expectancies at age 15 that vary between 39 and 62 years. The mean age at childbearing of mothers, $\bar{M}$, falls between 23.5 and 31.5 years, while that of fathers ranges from 30.1 to 41.0 years with averages of 27.3 and 35.2 years respectively.

To evaluate Equation (3), it is also necessary to model the distribution of women's ages at marriage. It turns out that, for respondents in the age range in which most marriages occur, the proportion orphaned at marriage is extremely sensitive to the exact shape of the first-marriage distribution. At these ages it is impossible to control for the age pattern of marriage sufficiently accurately to estimate mortality. Acceptably robust estimates can only be obtained from age groups in which nearly all women are married. For respondents aged 25 and over, in contrast, a simple control for the mean age at marriage allows one to estimate mortality reliably. Almost identical results are obtained, whatever assumptions are made about the shape of the distribution of first marriages.[19] Thus, even if the ages at which women marry have been rising, mortality can be estimated if the mean age at marriage of each cohort is known. In addition, in models of the form that are proposed here, the relationship between the mean age at marriage and the predicted life-table measures is close to linear. Coefficients for orphanhood since marriage can be estimated by using three marriage distributions in which the mean age at marriage, $\bar{m}$, spans the range found in most developing countries. Very little would be gained by including populations in which the variance of the marriage distribution is different.

The distributions used to derive the simulated populations are Coale and McNeil's marriage models.[20] The parameters were chosen to produce marriage distributions with means of 15, 20 and 25 years (see Table 1). Thus, the coefficients for maternal

[16] See I. Timæus, '*Advances in the Measurement of Adult Mortality from Data on Orphanhood*'. CP5 Research Paper 90–1 (London School of Hygiene and Tropical Medicine 1990) in which the choice of parameters and characteristics of the resulting populations are discussed at greater length.

[17] See W. Brass 'On the scale of mortality', in W. Brass (ed.), *Biological Aspects of Demography* (Taylor and Francis, London, 1971).

[18] These standards were developed for use in populations with high fertility. The new standard for males was constructed by 'stretching' the standard for females to age 80. It performs remarkably well. See H. Booth, 'Transforming Gompertz's function for fertility analysis: the development of a standard for the relational Gompertz function', *Population Studes*, **38** (1984), pp. 495–506. W. J. Paget and I. M. Timæus, *A Relational Gompertz Model of Male Fertility: Development and Application to Time Location Procedures.* CPS Research Paper 90–2 (London School of Hygiene and Tropical Medicine, London, 1990)

[19] This can be verified by comparing estimates obtained using the coefficients for orphanhood since marriage, for a mean age at marriage of 20 years, with those obtained from the same data using the coefficients for orphanhood since age 20 published in Timæus, *loc. cit.* in fn. 3. The latter coefficients are equivalent to those for orphanhood since marriage in a population in which all women marry at the same age.

[20] See A. J. Coale and D. R. McNeil, 'The distribution by age of the frequency of first marriage in a female cohort', *Journal of the American Statistical Association*, **67** (1972), pp. 185–258.

Table 1. *Parameters that define the simulated populations for estimation of the relationship between parental survival and life-table measures*

(*a*) Mortality	$\alpha = 0.2, -0.2, -0.6, -1.0$ $\beta = 0.8, 1.1$
(*b*) Fertility (females)	$\alpha_f = -0.5, -0.2, 0.1, 0.4$ $\beta_f = 0.7, 1.0, 1.3$
(*c*) Fertility (males)	$\alpha_f = -0.4, -0.1, 0.2, 0.6$ $\beta_f = 0.7\ (\alpha_f < 0.6), 1.0, 1.3\ (\alpha_f > -0.4)$
(*d*) Marriage	$a_0 = 8.75, 13.75, 18.75$ $k = 0.55$

orphanhood since marriage are based on 288 populations, and those for paternal orphanhood on 240 sets of data.

Earlier research has shown that life-table survivorship can be estimated from data on the survival of mothers by a regression model that includes a control for the mean age at childbearing.[21] In contrast to the estimation of women's mortality from lifetime data on parental survival, a model which incorporates measures of parental survival in two adjoining age groups produces more accurate estimates of life-table survivorship from data on orphanhood since marriage, than a model in which information on just one age group is used. The improvement in fit is particularly large for estimates from data on younger respondents. Part of the explanation why information on an additional age group proves valuable is that it renders the method more robust to unusual age patterns of childbearing and mortality.[22] In addition, the second age group captures the impact of an interaction between the level of parental survival and the timing of marriage. A model in which a term for ${}_5S_n$ is included, however, explains more of the variation in the life-table survivorship ratio than one that includes an interaction term of the form $m\,.\,{}_5S_{n-5}$. Moreover, the latter term has a distinctly non-linear relationship with the dependent variable.

Because of the sensitivity of estimates for younger respondents to the age pattern of marriage, the earliest central age of respondents, n, for which a survivorship ratio, ${}_np_b$, can be estimated from data on orphanhood since marriage is 30 years. To preserve a close relationship between parental survival and life-table survivorship, the latter is measured from a base age, b of 45 years. Thus, the model used to estimate life-table measures from the survival of mothers since the respondents married is:

$$l(25+n)/\,l(45) = \beta_0(n)+\beta_1(n)\,\bar{M}+\beta_2(n)\,\bar{m}+\beta_3(n)\,{}_5S_{n-5}/{}_5S^m_{n-5}+\beta_4(n)\,{}_5S_n/{}_5S^m_n.$$

The only differences in the equation for the estimation of men's mortality from paternal orphanhood since marriage arise because men are, on average, about ten years older than women at the birth of their children. The estimates are made using:

$$l(35+n)/\,l(55) = \beta_0(n)+\beta_1(n)\,\bar{M}+\beta_2(n)\,\bar{m}+\beta_3(n)\,{}_5S_{n-5}/{}_5S^m_{n-5}+\beta_4(n)\,{}_5S_n/{}_5S^m_n.$$

Coefficients are presented for estimating survivorship over the age ranges ${}_{10}p_{45}$ to ${}_{30}p_{45}$ for females and ${}_{10}p_{55}$ to ${}_{20}p_{55}$ for males.

The accuracy of mortality estimates produced using the coefficients for orphanhood

[21] See K. Hill and T. J. Trussell, 'Further developments in indirect mortality estimation', *Population Studies*, **31** (1977), pp. 313–333. A. Palloni and L. Heligman, 'Re-estimation of the structural parameters to obtain etimates of mortality in developing countries', *Population Bulletin of the United Nations*, **18** (1986), pp. 10–33. Timæus, *op. cit.* in fn. 16.

[22] This consideration is particularly important for the estimation of men's mortality, see Timæus, *op. cit.* in fn. 16.

since marriage is broadly similar to that of those from the basic method.[23] The loss of precision involved in modelling the first-marriage distribution is largely offset by the fact that survivorship is being estimated over a more limited range of ages. When the coefficients were used to estimate mortality from further simulated data, including those on populations with extreme characteristics, the errors in the results seldom represented biases in measures of life expectancy at age 15 of more than one year. In some populations, the estimates from the coefficients for paternal orphanhood since marriage fell between one and two years of the correct value. In addition, these coefficients should only be used when the mean age at fatherhood lies between 31 and 37 years.

III. ORPHANHOOD BEFORE MARRIAGE

Estimation of adult mortality from orphanhood before marriage is based on Equation (2). The equivalent relationship for five-year age groups of respondents is:

$$ {}_5S_x^m = \frac{\int_x^{x+5} l(a) \int_0^a m(z) \int_s^w {}_z v_y \cdot {}_z p_y \, dy \, dz \, da}{\int_x^{x+5} l(a) \int_0^a m(z) \, dz \, da}. \tag{4} $$

For age groups of women who are still marrying, this relationship changes slightly with age. However, in a stable population, exactly the same proportion of women will have been orphaned before marriage in all age groups above the oldest age at which first marriages occur.

Coefficients for the estimation of men's and women's adult mortality from orphanhood before marriage are also presented in the Appendix. They were derived from the same simulated data and methods as the coefficients for estimating mortality from orphanhood since marriage. The sensitivity of the level of orphanhood since marriage to the age pattern of marriage among women aged less than 25 years is mirrored in data on orphanhood before marriage. Therefore, coefficients are only presented for use with data supplied by respondents older than 25 years. Because the responses of each age cohort reflect the survival of parents over more or less the same range of ages at different points in time, there is nothing to be gained by using information on more than one age group to make the estimates. Experimentation with different models again indicates that the relationship between parental survival and life-table survivorship depends on the timing of marriage. For orphanhood before marriage, however, an interaction term between the mean age at marriage and proportion with living parents improves the fit of the model more than for orphanhood since marriage. Moreover, in this case, the interaction term is linearly related to the dependent variable. Thus, the probability of surviving from age 25 to age 45 for women can be estimated from orphanhood before marriage using:

$$ l(45)/l(25) = \beta_0(n) + \beta_1(n)\bar{M} + \beta_2(n)\bar{m} + \beta_3(n)\,{}_5S_n^m + \beta_4(n)\,\bar{m}\,{}_5S_n^m. $$

The same considerations apply to the estimation of adult men's mortality from paternal orphanhood before marriage. Estimates of the probability of surviving from age 35 to age 55 are made from:

$$ l(55)/l(35) = \beta_0(n) + \beta_1(n)\bar{M} + \beta_2(n)\bar{m} + \beta_3(n)\,{}_5S_n^m + \beta_4(n)\,\bar{m}\,{}_5S_n^m. $$

[23] *Ibid.* With accurate reporting, the coefficients for maternal orphanhood are very precise. Although those for paternal orphanhood perform less well, they are more accurate than the general tenor of the literature suggests.

The accuracy of estimates from this method is similar to that of those from orphanhood since marriage. In other variants of the orphanhood method, the accuracy with which mortality can be estimated declines as the age of respondents, and therefore that of their parents, increases.[24] For orphanhood before marriage this problem does not arise. The estimates from respondents of all ages are based largely on the experience of young and middle-aged parents. In theory, the final sets of coefficients presented in the appendix for maternal and paternal orphanhood before marriage can be used to estimate mortality from the reports of any age group of respondents aged 40 and above. Only the accuracy of reporting about parental deaths and respondents' own ages imposes an upper age limit on the data on orphanhood before marriage that can be used to estimate mortality.

IV. TIME LOCATION OF THE ESTIMATES

Like those from lifetime orphanhood, estimates made from the data supplied by different age cohorts of respondents about orphanhood before and after marriage, reflect mortality over varying and ill-defined periods of time. For the basic method, each cohort estimate of mortality equals the equivalent period-measure of mortality at a weighted average of the intervals since death of the parents.[25] The interval since this time, ${}_{N}g_{a}$, is determined largely by the mean age at which exposure starts, a; the average duration of exposure, N; and the level of mortality and, therefore, parental survival. It can, therefore, be estimated and the data obtained from respondents of different ages used to measure the trend in mortality over time.

The same principles apply to information on orphanhood before marriage and orphanhood since marriage. The procedure developed by Brass and Bamgboye for estimating the time location of adult mortality estimates calculated from lifetime orphanhood and widowhood,[26] can also be used to calculate the time-reference of mortality measures obtained from these sources. The justification for this is clear if the discussion in Section I is recalled. The proportion of women orphaned before marriage is similar to the overall proportion of female respondents orphaned in the age group which encompasses the mean age at marriage of women in the population concerned. In general terms, the distribution of intervals between orphanhood and marriage is also similar to the distribution of intervals between orphanhood and the time of interview for women whose age is the same as the mean age at marriage. Thus, reasonable estimates of the time-location of estimates made from data on orphanhood before marriage can be obtained using the method developed by Brass and Bamgboye for orphanhood at all ages. Similar considerations apply to estimates from orphanhood since marriage. These data are similar in form and characteristics to those which concern the proportion of women whose first husbands have died, in populations in which men marry at much later ages than women.[27] Once again, use of the procedure developed by Brass and Bamgboye seems justified.[28]

[24] *Ibid.*, Palloni and Heligman, *loc. cit.* in fn. 21.

[25] See W. Brass and E. Bamgboye, *The Time Location of Reports of Survivorship: Estimates for Maternal and Paternal Orphanhood and the Ever-Widowed.* CPS Research Paper, 81-1 (London School of Hygiene and Tropical Medicine, London, 1981).

[26] *Ibid.*

[27] Brass, *op. cit.* in fn. 10.

[28] Appreciable increases in the overall accuracy of the time references calculated for indirect estimates of adult mortality could probably be achieved by replacing the adjustment factors proposed by Brass and Bamgboye, by separate adjustments for use with data on maternal orphanhood, paternal orphanhood, and widowhood respectively (Timæus, *op. cit.* in fn. *). No doubt tailor-made procedures would also produce better results for orphanhood before and since marriage. Nevertheless, the generic method is adequate for the initial assessment of the characteristics and value of mortality estimates made from these new forms of orphanhood data.

For orphanhood before marriage, the time-reference of the mortality measures is a convolution of the distribution of intervals between parental deaths and marriage and the distribution of intervals between marriage and interview. To the degree of precision required, the time references for maternal orphanhood equal the sum of the mean interval from marriage to interview and the mean interval since orphanhood at the time of first marriage. For cohorts of women who have nearly all married, the ages at which the parents are exposed to the risk of dying are concentrated between the mean age at childbearing and the sum of that age and their daughters' mean age at first marriage. Using the notation already established, the time-reference of the mortality measures can be calculated as:

$$T = (N - \bar{m}) + {}_{\bar{m}}g_{\bar{M}}. \tag{5}$$

The second term on the right hand side of Equation (5) can be estimated by using the procedure proposed by Brass and Bamgboye.[29] As for lifetime orphanhood, the time reference of estimates of men's mortality should allow for deaths between conception and birth and are calculated by using ${}_{\bar{m}+0.75}g_{\bar{M}-0.75}$.

For orphanhood since marriage, the age at which parents enter exposure to the risk of death is a convolution of their distribution of ages at childbearing and their daughters' ages at marriage. Following Brass and Bamgboye's argument, for age groups that have largely completed marriage it is justifiable to estimate the mean age at which exposure starts as the sum of the means of these two distributions. The parents' exposure continues till the time of interview, $N - \bar{m}$ years later. Thus the time-references of the mortality measures are:

$$T = {}_{N-\bar{m}}g_{\bar{M}+\bar{m}}. \tag{6}$$

They can also be estimated by using the procedure proposed by Brass and Bamgboye.[30] Because the age range over which fathers are exposed to the risk of death commences well after the birth of their daughters, Equation (6) is appropriate for estimates of both men's and women's mortality.

V. APPLICATIONS

Estimates of adult mortality from data on parental survival since marriage in Morocco, collected in the survey conducted in 1987 as part of the DHS programme, are shown in Table 2. The life-table indices have been calculated using the coefficients presented in the Appendix and the time-reference of the estimates from Equation (6), using the adjustment factors proposed by Brass and Bamgboye.[31] The results are translated into α, the level parameter of the relational logit system of model life tables based on the General Standard.[32]

In Morocco, cross-sectional data on marital status yield a mean age at marriage for women in excess of 21 years. However, ages at marriage are known to have risen in Morocco in recent years. The dates of marriage reported retrospectively by women aged 25 years and over in the DHS indicate that they married at younger ages than is suggested by the cross-sectional data. As the mean ages at marriage reported by different cohorts are very similar, an average of 18.3 years, calculated from data relating to respondents aged 25–44 years, was used to produce all the estimates of mortality.

It can be seen from Table 2 that the time-references of all the mortality estimates fall within a period that is little more than three years long. Given the nature of the data and method, it seems unlikely that the results are sufficiently accurate to detect trends in

[29] Brass and Bamgboye, *op. cit.* in fn. 25.
[30] *Ibid.* [31] *Ibid.* [32] W. Brass, *loc. cit.* in fn. 17.

Table 2. *Estimation of adult mortality from orphanhood since marriage, Morocco*

Age (n)	Proportion not orphaned since marriage ${}_5S_{n-5}/{}_5S^m_{n-5}$	$\frac{l(b+n)}{l(b+20)}$ ($\bar{m}$ = 18.3)	α	Date
	Women's mortality (b = 25, $\bar{M}$ = 28.3)			
30	0.9650	0.9564	−0.997	1982.9
35	0.9083	0.8997	−0.862	1981.4
40	0.8022	0.8638	−1.002	1980.3
45	0.7234	0.7927	−1.061	1979.8
50	0.6114			
	Men's mortality (b = 35, $\bar{M}$ = 36.67)			
30	0.8801	0.8567	−0.736	1983.4
35	0.7574	0.7498	−0.793	1982.1
40	0.6133	0.6119	−0.875	1981.2
45	0.4919			

adult mortality over such a brief period. Thus, the best way to treat these estimates is probably to average those that seem most reliable to produce a single estimate of mortality. In most applications it would be sufficiently accurate to take this average as applying to a date six years before the data were collected. In Morocco, another consideration supports this argument. The estimates of mortality for both males and females from older respondents indicate significantly lighter mortality than those obtained from the first couple of age groups. This is unlikely to be a real trend. Moreover, it cannot be the product of an increase in ages at marriage across the cohorts, as this would produce a bias in the opposite direction. The most likely explanation of this apparent trend is age exaggeration by older respondents. Estimates from orphanhood since marriage are more sensitive to age-reporting errors than those from lifetime orphanhood because they are based on parental exposure at relatively advanced ages. In addition, the first estimate for females is a little high, while in some of the applications presented later it is rather low. This is probably because the number of deaths on which this proportion is based is fairly small.

Estimates of adult mortality in Morocco from the data on orphanhood before marriage collected in the DHS survey are shown in Table 3. They have been obtained by using the second two sets of coefficients presented in the appendix. The time-reference of the measures was estimated on the basis of Equation (5). It is clear from the differences by age in the proportions of respondents with surviving mothers and fathers at marriage that a substantial decline in adult mortality has occurred in Morocco. This is confirmed by the estimated life-table measures and the values of α derived from them. The time-reference of the estimates based on respondents aged 25–29 years, who married around nine years before the survey, is about 17 years before the time that the data were collected. As one would expect, the time-reference of each of the following estimates is about five years earlier than the previous one. The estimates from respondents aged 45–49 years measure the level of adult mortality more than 37 years before the data on orphanhood before marriage were collected.

These estimates of mortality from orphanhood before and after marriage in Morocco are shown in Figure 1, together with the estimates from lifetime orphanhood according to the World Fertility Survey (WFS) and DHS surveys.[33] Comparison of the two sets of

[33] See M. Al-Jem, I. Timæus and S. Aoun, 'La mortalité au Maroc d'après des résultats de l'ENPS', in A. G. Hill (ed.), *Determinants of Health and Mortality in Africa* (The Population Council, and IRD Macro, New York, 1990).

Table 3. *Estimation of adult mortality from orphanhood before marriage, Morocco*

Age (n)	Proportion not orphaned before marriage ${}_5S_n^m$	$\frac{l(b+20)}{l(b)}$ ($\bar{m}$ = 18.3)	α	Date
	Women's mortality (b = 25, $\bar{M}$ = 28.3)			
25	0.9199	0.9248	−0.659	1970.2
30	0.8985	0.9051	−0.514	1965.2
35	0.8947	0.9019	−0.493	1960.1
40	0.8496	0.8562	−0.226	1954.9
45	0.7981	0.8038	0.033	1949.8
	Men's mortality (b = 35, $\bar{M}$ = 36.67)			
25	0.8522	0.8782	−0.628	1970.4
30	0.8229	0.8490	−0.479	1965.3
35	0.8002	0.8246	−0.366	1960.2
40	0.7980	0.8222	−0.356	1955.2
45	0.6952	0.7092	0.120	1949.8

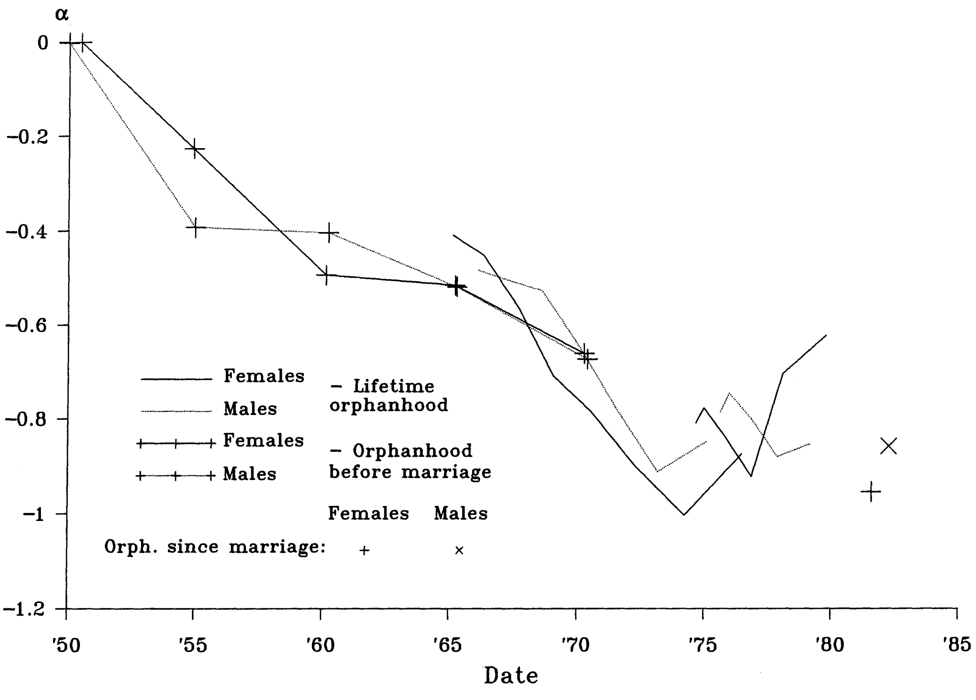

Figure 1. Adult mortality (α) estimated from orphanhood before and since marriage, Morocco.

lifetime data suggests that the more recent estimates from the WFS may be biased downward somewhat by the adoption effect. In addition, in the DHS survey a sample of ever-married women was interviewed. Early marriage is associated with both maternal and paternal orphanhood in Morocco. This biases the DHS data on the survival of parents downward for respondents aged less than 25 years, resulting in the sharp recent increase in women's mortality indicated by these data and the smaller upturn in the most recent DHS estimate for males.

The existence of an association between orphanhood and entry into marriage in

Morocco breaches one of the assumptions made in the derivation of the coefficients for estimating life-table measures from orphanhood before and after marriage.[34] The strength of the association is difficult to determine, but can be gauged in broad terms from Table 4. This table compares the prevalence of orphanhood at marriage, reported retrospectively by women interviewed in the DHS who married between mid-1977 and mid-1982, with cross-sectional data on women of all marital statuses according to the WFS survey conducted at the end of 1979. Although the WFS data may be biased upwards by the adoption effect and the DHS figures are based on fairly small numbers, it is clear that women who married at young ages in Morocco are more likely to have lost a parent than other girls of their age. The extent to which this happens because high mortality and early marriage are concentrated among the rural poor, and the extent to which orphanhood itself causes early marriage would be difficult to establish from the relatively small, cross-sectional DHS survey, but does not matter for the current analysis.

Table 4. *Percentages by age of all women, and of women who marry, with living fathers and mothers, Morocco 1979*

Age group	All (WFS)	Women who marry (DHS)
Percentage with mother alive		
10–14	97	91
15–19	95	93
20–24	91	90
Percentage with father alive		
10–14	93	87
15–19	87	88
20–24	80	82

If mortality was estimated from orphanhood before and since marriage of cohorts of women who had not largely completed entry into marriage, the association between ages at marriage and orphanhood would introduce a major bias into the results. For respondents aged 25 and over, this is less of a problem. What the association does imply, however, is that aggregate data on ages at marriage misrepresent the length of time for which parents have been exposed to the risk of dying. For orphanhood before marriage the bias is not of any significance. The estimates are extremely robust to the exact shape of the marriage distribution, and the shorter-than-average potential exposure of the parents who died before their daughters married is offset by the longer exposure of parents who were alive when their daughters married. The impact of the bias is also limited for orphanhood since marriage, because the majority of parents are alive when their daughters marry. Although, on average, parents who live till their daughters marry are exposed for a shorter period subsequently than is indicated by the overall mean age at marriage, in Morocco the mean ages at marriage of women with surviving fathers and mothers only differ by 0.05 years from the overall mean age at first marriage. The bias that results from using an estimate of $\bar{m}$ which applies to the whole population is minimal. Given the enormous demographic differentials that exist between the urban and rural areas and the educated and uneducated in Morocco,[35] it seems probable that the association between marriage and orphanhood is particularly strong in this country.

[34] See Section II.

[35] Al-Jem *et al., loc. cit.* in fn. 33.

For example, in the DHS data on Burundi, discussed next, the tendency for orphaned women to marry early is weaker. It is thus unlikely that this problem will prove a significant source of bias in mortality estimates from orphanhood before and since marriage.

The other assumption, in addition to those involved in the basic orphanhood method, made to derive coefficients for estimating mortality from orphanhood relative to marriage, is that women's ages at marriage are unrelated to their parents' ages. In many populations such a relationship probably exists. For example, the youngest daughter may tend to remain at home to look after her ageing parents. Despite this, in light of the discussion of the impact on the results of any association between orphanhood and age at marriage, it seems unlikely that breaches of this second assumption are a significant source of bias in estimates of mortality from orphanhood relative to marriage.

The results shown in Figure 1 are most encouraging. The information on orphanhood before and since marriage eases interpretation of the results based on lifetime orphanhood, and provides estimates for a much longer span of time than the basic method. In particular, the information on orphanhood since marriage yields mortality estimates that are at least five years more up to date than the most recent acceptable estimates from the data on lifetime orphanhood collected in the DHS survey. The estimates made from lifetime data on older respondents in the WFS and the DHS, and those from orphanhood since marriage, form fairly consistent series for both men's and women's mortality. If anything, the estimates from orphanhood since marriage suggest rather higher mortality than the trend in the lifetime data. They indicate that life expectancy at age 15 in the early 1980s was a little under 58 years, compared with an estimate from the WFS, 15 years earlier, of about 51 years. In broad terms, the estimates from orphanhood before marriage, according to the DHS, provide confirmation of the earlier estimates from the WFS. These data indicate slightly lower mortality than the trend in the more recent figures but, given that the estimates from older respondents are probably biased downward to some extent by age exaggeration, they offer good evidence that a prolonged decline in adult mortality has occurred in Morocco, from a very high level at the beginning of the 1950s.

Estimates of mortality in Burundi from orphanhood before and after marriage and other sources are shown in Figure 2. The estimates from the 1971 multi-round survey are based on published data[36] and the orphanhood estimates on data collected in the DHS survey in Burundi.[37] In this survey a question was asked about dates of orphanhood, the answers to which made it possible to calculate synthetic cohort measures from orphanhood after age 20.[38] For about 25 per cent of respondents the date of orphanhood had to be estimated, which is likely to bias the most recent estimates upwards.[39] This seems to have occurred; but, in addition, the estimates for the period five to nine years before the survey appear biased in the opposite direction. This suggests that these period estimates are affected by errors in the reporting of dates of orphanhood. In this survey, dates of orphanhood seem to have been shifted forward. The data on deaths of fathers are more affected than those on deaths of mothers.

As in Morocco, the results obtained from orphanhood before and since marriage seem very useful and provide a much sounder basis for determining the level and trend in adult mortality in Burundi than if only data on lifetime orphanhood and the multi-

[36] See J. Condé, M. Fleury-Brousse and D. Waltisperger, *Mortality in Developing Countries* (OECD, Paris, 1980).

[37] C. Makinson, personal communication.

[38] Chackiel and Orellana, *loc. cit.* in fn. 6. Timæus, (1991) *loc. cit.* in fn. 3.

[39] C. Makinson, personal communication.

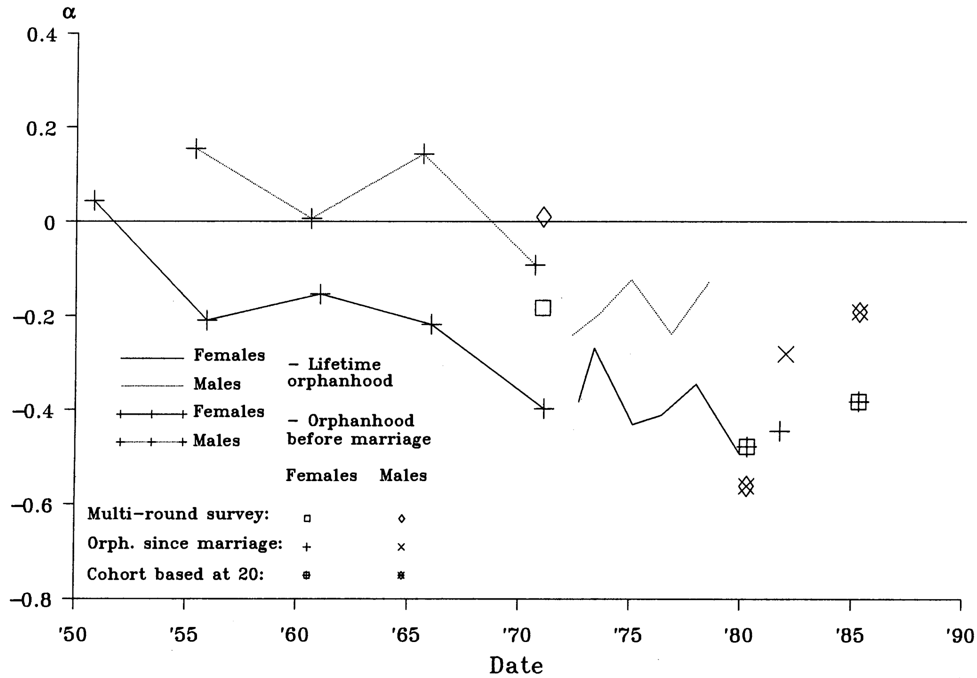

Figure 2. Adult mortality (α) estimated from orphanhood before and since marriage, Burundi.

round survey results were available. Although the estimates from lifetime orphanhood and orphanhood before marriage are rather erratic, they agree well for both males and females and offer clear evidence that, while adult mortality in Burundi remains fairly high, it has declined slowly from the early 1950s to the late 1970s. If the data from the multi-round survey can be relied upon, they indicate that these orphanhood estimates understate the life expectancy of young adults by a modest amount.

Extrapolating forward from the estimates from the multi-round survey, on the basis of the trend in the data on lifetime orphanhood and orphanhood before marriage, it seems likely that the estimates from orphanhood since marriage are fairly accurate. They yield a life expectancy at age 15 for the early 1980s of 49 years, compared with 45 years for 1971. Although the estimates from orphanhood after age 20 are clearly only partially independent of the estimates from orphanhood since marriage, averaging the points for 0–4 years and 5–9 years before the survey also suggests that the latter results are reasonably accurate.

In Figure 3, results are presented from a survey conducted in parts of the Buganda and Basoga regions of Uganda. In this survey respondents were also asked about dates of orphanhood and synthetic cohort estimates calculated from orphanhood after age 20 are included in the figure.[40] The parental survival data from this survey appear to be severely biased by the adoption effect. The estimates made from lifetime orphanhood are implausible, and only a small proportion of respondents in this survey reported that they had been orphaned before marriage.[41] These data did not yield useful estimates of adult mortality. The estimates from orphanhood since marriage are more plausible than any

[40] Chackiel and Orellana, *loc. cit.* in fn. 6. Timæus, (1991) *loc. cit.* in fn. 3.

[41] This confirms that adults who were orphaned at young ages tend to answer questions about orphanhood in terms of their foster- or step-parents. In this part of Uganda at least, errors stemming from the adoption effect are not limited solely to proxy reports on behalf of young children.

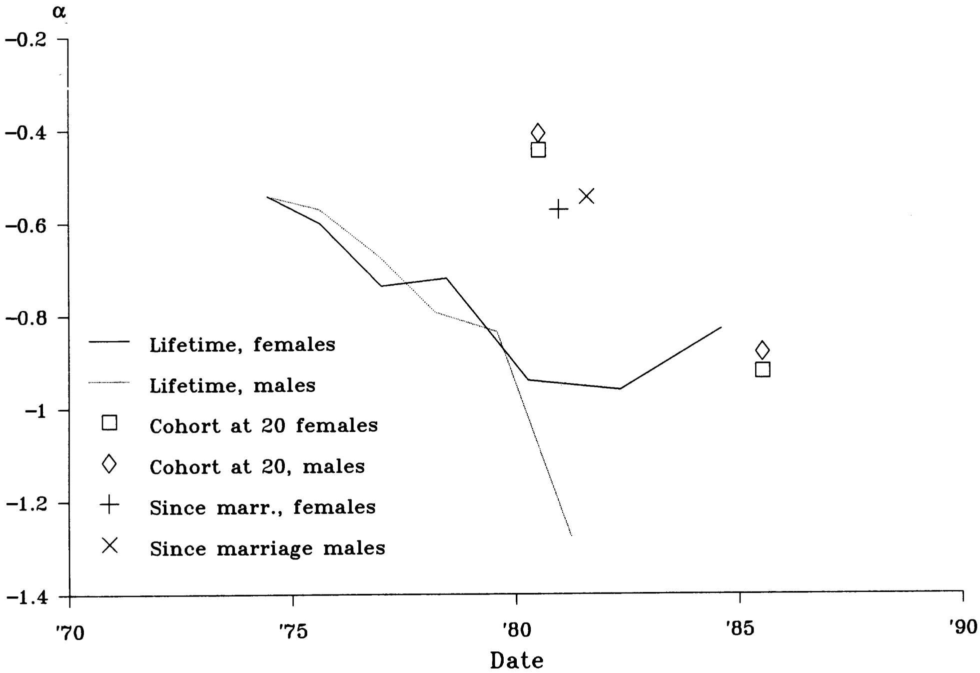

Figure 3. Adult mortality (α) estimated from orphanhood before and since marriage, Buganda/Basoga.

of the other estimates. Although there is no independent source of data against which they can be validated, they indicate very similar mortality for males and females and much higher mortality than the estimates from lifetime orphanhood. Thus, although some of the 'parents' that were alive when these women married may not be their biological genitors, it does not appear that adults are liable to redefine someone else as their parent when the person who reared them as a child has died. The values of α obtained from the data on orphanhood since marriage correspond to an expectation of life at age 15 of about 52 years, an estimate which seems reasonable for the early 1980s. Partial confirmation of the estimates from orphanhood since marriage is provided by the fact that they fall between the two sets of points obtained from orphanhood after age 20.[42]

VI. CONCLUSIONS

The development of coefficients for orphanhood since marriage provides, for the first time, a convenient way of estimating mortality from a novel form of data. The initial applications of this procedure, presented here, provide only a tentative basis for assessing the usefulness of the method. Nevertheless, the results are very encouraging. In these three analyses, mortality estimates from orphanhood since marriage are either consistent with the other estimates available, or seem more believable than they are. Moreover, the sex differentials in adult mortality indicated by these data are plausible and agree closely with those from other sources.

These applications also demonstrate four important potential advantages of data on

[42] It is likely, though, that errors in the retrospective reporting of dates have resulted in an exaggeration of the decline in mortality in this region.

orphanhood since marriage for the estimation of adult mortality. First, these data make it possible to estimate mortality about five to six years before the survey even if, as in the studies conducted by the DHS, only respondents aged 15 and over are asked about the survival of their parents. Secondly, a question on the timing of orphanhood relative to marriage seems a more robust way to refine the time-reference of the mortality estimates than a question on the dates when respondents were orphaned. The latter question appears to have been badly affected by errors in the retrospective reporting of dates in the surveys in both Burundi and Uganda. In the former, it was also subject to a high degree of item non-response. Collection of data on orphanhood relative to marriage makes fewer demands on the respondents. Thirdly, data collected in surveys in which only ever-married women are interviewed are vulnerable to selectivity bias, that results from association of women's ages at marriage with orphanhood. Estimates based on information supplied by older respondents about orphanhood relative to marriage are less liable to bias from this source. Fourthly, the application to Ugandan data suggests that, in countries where the basic data on the survival of parents are biased severely by underreporting of the incidence of orphanhood in childhood, it may be possible to collect much more accurate data on orphanhood since marriage.

One problem with this method of estimating mortality that these initial applications have shown, on the other hand, is that the initial estimate for a central age, n, of 30 years tends to be rather erratic, probably because of sampling errors, while the estimates based on older age groups are sensitive to age exaggeration by respondents. Thus mortality estimates have to be based on the information supplied by respondents in a narrow range of ages. Nevertheless, these applications indicate that the method has promise as a simple, affordable way of estimating adult mortality at a date about six years before to a single-round survey.

Questions on the timing of orphanhood relative to marriage also make it possible to estimate adult mortality from orphanhood before marriage. Coefficients are also presented to facilitate the analysis of such data. In some populations, the quality of the data on orphanhood before marriage is evidently very poor. This is almost certainly due to the adoption effect. Elsewhere, the results seem very plausible. Thus, in Uganda these data were useless but, in Morocco and Burundi, they appear to be reasonably accurate, although they probably slightly underestimate orphanhood in childhood.

When the data are not biased by the adoption effect, this variant of the orphanhood method has two valuable characteristics. First, it measures mortality over a limited and fairly clearly defined interval of time and range of ages. Secondly, the estimates provide useful confirmation of the trend in mortality indicated by data on lifetime orphanhood, and seem capable of extending the time series of mortality estimates provided by the orphanhood method backward to a period at least 30 or 35 years before the data were collected. It is likely that selectivity biases that are caused by any association between the mortality of parents and children become increasingly severe as the age of respondents increases, and a rising proportion of them die themselves. Nevertheless, it is possible that, in populations where older people report their age reasonably accurately, data on orphanhood before marriage could be used to reconstruct the trend in mortality over a period of 50 or more years.

Indirect methods of estimation cannot supply the detailed age-specific and time-specific measures of mortality that are produced by adequate vital statistics systems. In general, however, rather broad indicators of the level and trend in adult mortality will serve for the formulation of health policy, the allocation of resources, and population forecasting. Indirect methods can provide such information from answers to straightforward questions that can be posed in single-round surveys of a moderate size.

When the questions are asked in censuses, orphanhood data can be used estimate mortality in districts, or other small geographical areas. The additional questions proposed here, whether women's parents had died before or after the respondents first married, are short, can be administered quickly, and are easy to answer. It seems likely that the collection and analysis of such data could make a valuable contribution to our knowledge of levels and trends in adult mortality in developing countries, especially in populations in which the basic orphanhood method is affected adversely by the adoption effect.

APPENDIX: COEFFICIENTS FOR ORPHANHOOD ESTIMATION

A.1. *Coefficients for maternal orphanhood after marriage*

Estimation of $l(25+n)/l(45)$ from proportions of mothers alive among women with living mothers when they married

$$l(25+n)/l(45) = \beta_0(n)+\beta_1(n)\bar{M}+\beta_2(n)\bar{m}+\beta_3(n)\,{}_5S_{n-5}/{}_5S^m_{n-5}+\beta_4(n)\,{}_5S_n/{}_5S^m_n.$$

n	$\beta_0(n)$	$\beta_1(n)$	$\beta_2(n)$	$\beta_3(n)$	$\beta_4(n)$	R^2
30	0.5617	0.00836	−0.00261	−1.1231	1.4199	0.964
35	0.0476	0.01396	−0.00536	−0.3916	1.1354	0.966
40	−0.3715	0.01966	−0.00744	0.5394	0.5286	0.976
45	−0.6562	0.02587	−0.00716	1.0208	0.1789	0.987
50	−0.8341	0.03045	−0.00561	1.1898	0.0541	0.990

A.2. *Coefficients for paternal orphanhood after marriage*

Estimation of $l(35+n)/l(55)$ from proportions of fathers alive among women with living fathers when they married

$$l(35+n)/l(55) = \beta_0(n)+\beta_1(n)\bar{M}+\beta_2(n)\bar{m}+\beta_3(n)\,{}_5S_{n-5}/{}_5S^m_{n-5}+\beta_4(n)\,{}_5S_n/{}_5S^m_n.$$

n	$\beta_0(n)$	$\beta_1(n)$	$\beta_2(n)$	$\beta_3(n)$	$\beta_4(n)$	R^2
30	0.0795	0.01588	−0.00633	−1.2070	1.8284	0.979
35	−0.5289	0.02273	−0.01083	−0.2509	1.3867	0.980
40	−0.8477	0.02622	−0.01135	0.6057	0.7198	0.974

A.3. *Coefficients for maternal orphanhood before marriage*

Estimation of $l(45)/l(25)$ from proportions of women with living mothers when they married

$$l(45)/l(25) = \beta_0(n)+\beta_1(n)\bar{M}+\beta_2(n)\bar{m}+\beta_3(n)\,{}_5S^m_n+\beta_4(n)\,\bar{m}\,{}_5S^m_n.$$

n	$\beta_0(n)$	$\beta_1(n)$	$\beta_2(n)$	$\beta_3(n)$	$\beta_4(n)$	R^2
25	−0.9607	0.00418	0.04466	1.8178	−0.04291	0.988
30	−0.9921	0.00429	0.04700	1.8428	−0.04501	0.988
35	−1.0129	0.00433	0.04822	1.8607	−0.04611	0.988
40+	−1.0206	0.00434	0.04861	1.8680	−0.04648	0.988

A.4. *Coefficients for paternal orphanhood before marriage*

Estimation of $l(55)/l(35)$ from proportions of women with living fathers when they married

$$l(55)/l(35) = \beta_0(n) + \beta_1(n)\,\bar{M} + \beta_2(n)\,\bar{m} + \beta_3(n)\,{}_5S_n^m + \beta_4(n)\,\bar{m}\,{}_5S_n^m.$$

n	$\beta_0(n)$	$\beta_1(n)$	$\beta_2(n)$	$\beta_3(n)$	$\beta_4(n)$	R^2
25	−1.2640	0.01060	0.04480	1.8383	−0.04007	0.969
30	−1.2897	0.01068	0.04652	1.8530	−0.04124	0.969
35	−1.3123	0.01070	0.04769	1.8726	−0.04225	0.970
40+	−1.3152	0.01070	0.04783	1.8753	−0.04238	0.970