Chapter IV

ESTIMATION OF ADULT SURVIVORSHIP PROBABILITIES FROM INFORMATION ON ORPHANHOOD AND WIDOWHOOD

A. BACKGROUND OF METHODS

1. *Nature and use of indirect information on adult mortality*

Chapter III describes how information on the survival of close relatives—information from mothers about the survival of their children—can be used to make indirect estimates of child mortality. The principle can be extended to information about the survival of other close relatives. This chapter describes procedures for obtaining estimates of adult mortality from information concerning the survival of parents and the survival of spouses. In both cases, a particular target person is known to have been alive at the time of some past event (the birth of the respondent in the case of mothers, the conception of the respondent in the case of fathers and marriage in the case of spouses); and some information is available about both the length of exposure to the risk of dying and about the age at which the exposure began. Sample surveys are the usual source of the necessary data, though on occasion, the necessary questions have been included in censuses. The great advantage of these methods of mortality estimation is that they rely upon information gathered by questions that are simple and easy to answer. The normal forms of the questions on orphanhood are "Is your father alive?" and "Is your mother alive?", the possible answers being yes, no or not known. For widowhood, all ever-married respondents are asked whether their first spouse is still alive, the possible answers again being yes, no or not known. It should be mentioned that the term "orphanhood" is used in a rather unusual sense in this chapter, since it is specific to a parent's sex. Thus, when describing methods based on proportions with a surviving mother, an orphaned respondent is one whose mother has died, regardless of the father's survival.

Preston[1] points out that data on child survival collected from all women provide information about the overall proportion of persons in a given population with a surviving mother. In a closed population, the number of surviving children reported by all women, regardless of age, should be equal to the number of people in the population with a surviving mother. If no direct information on orphanhood is available, an estimate of the level of adult mortality can be made iteratively by finding the level of mortality that, when combined with the observed age distribution and age-specific fertility rates, produces the same overall proportion orphaned as the proportion calculated from child survival data. If data on the survival of mother are available, the consistency of the reported number of respondents with a surviving mother and the total reported number of surviving children can be checked; a tendency to omit surviving children will reduce the latter figure, and a tendency to report incorrectly a surviving mother will increase the former, so typical errors in the two types of data should show up clearly.

Information on the survival of parents or spouses is an indicator only of adult mortality, since the exposure to risk of the target person begins in adulthood, at the birth, conception or marriage of the respondent. Thus, strictly speaking, such data should be used only to estimate survivorship probabilities from one adult age to another; the first group of techniques presented in this chapter permits the estimation of such conditional survivorship probabilities, and the methods in this group are described as "conditional". However, if an estimate of the level of child mortality is available, in the form of an estimate of $l(2)$, and some assumption can be made about the form of the relationship between child and adult mortality in the population under study, the information on child mortality can be combined with an indicator of adult mortality to estimate an unconditional survivorship probability, that is, the probability of surviving from birth to some adult age. The second group of methods presented in this chapter, described as "direct" methods, allows the estimation of such unconditional survivorship probabilities. In choosing between these two approaches, it should be remembered that the estimates of conditional survivorship are less dependent upon assumed models, but they are also more difficult to incorporate into a full life table, than are the direct estimates, which, in turn, are determined, to a considerable extent, by the estimates of child mortality used in their calculation.

Estimates of adult mortality derived from information on the survival of close relatives represent averages of the mortality experienced over the period during which the relatives were exposed to the risk of dying. If mortality has been changing in a regular way, each estimate has a time reference; that is, there is a time before the survey with a period life table having the survivorship probability that has been estimated. The number of years, t, before the survey that define the period to which this life table refers will depend mainly upon the average exposure to risk of the target persons and upon

[1] Samuel H. Preston, "Estimating adult female mortality from reports on number of children surviving", University of Pennsylvania, Population Studies Center, 1980 (mimeographed).

the average age range of their exposure; in general, this number of years t will be somewhat less than half the average exposure to risk. It is possible to estimate the time period to which the survivorship probabilities derived from a single survey refer if certain assumptions about the regularity of the prevalent mortality trend are made. Brass and Bamgboye[2] propose such a method of estimation. In addition, when data are available from two surveys held five or 10 years apart, it is possible to derive estimates referring to the intersurvey period by reconstructing the experience of a hypothetical intersurvey cohort.

[2] William Brass and E. A. Bamgboye, "The time location of reports of survivorship: estimates for maternal and paternal orphanhood and the ever-widowed", Working Paper No. 81-1, London School of Hygiene and Tropical Medicine, Centre for Population Studies, 1981.

2. *Organization of this chapter*

All the estimation methods described in this chapter share two characteristics in common: they allow the estimation of probabilities of survivorship to ages in adulthood (beyond age 20); and they use data on the survival of close relatives (parents and spouses). The methods presented can be classified into several categories according to whether they permit the estimation of direct or conditional probabilities of survivorship

TABLE 85. SCHEMATIC GUIDE TO CONTENTS OF CHAPTER IV

Section	*Subsection and method*		*Type of input data*	*Estimated parameters*
B. Estimation of conditional adult survivorship	B.2(b)	Maternal orphanhood data: Brass method	Number of respondents with mother alive (or dead) classified by five-year age group Total number of respondents classified by five-year age group Number of respondents who did not know or did not state the survivorship status of their mothers Number of births occurring in a given year classified by five-year age group of mother	Probabilities of surviving from age 25 to ages 35, 40, 45, ..., 85 for females
	B.2(b)	Paternal orphanhood data: Brass method	Number of respondents with father alive (or dead) classified by five-year age group Total number of respondents classified by five-year age group Number of respondents who did not know or did not declare the survivorship status of their fathers Number of births occurring in a year classified by five-year age group of father (or of mother, if nothing else is available)	Probabilities of surviving from age 32.5 to ages 45, 50, 55, ..., 90; or the probabilities of surviving from age 37.5 to ages 50, 55, 60, ..., 95 (depending upon the value of M, the mean age of fathers at the birth of their children) for males
	B.2(c)	Maternal orphanhood data: regression method	Number of respondents with mother alive (or dead) classified by five-year age group Total number of respondents classified by five-year age group Number of respondents who did not know or did not declare the survivorship status of their mother Number of births occurring in a given year classified by five-year age group of mother	Probabilities of surviving from age 25 to ages 35, 40, 45, ..., 75 for females The time period to which each estimated probability refers when mortality is changing
	B.2(d)	Maternal orphanhood data from two surveys	Number of respondents with mother alive (or dead) classified by five-year age group, for two surveys five or 10 years apart Total number of respondents by five-year age group for the same two surveys Number of respondents who did not declare the survival status of their mother for the same two surveys Number of births occurring in a given year (preferably during the intersurvey period) classified by five-year age group of mother	Probabilities of surviving from age 25 to ages 35, 40, 45, ..., 75 for females during the intersurvey period

TABLE 85 (*continued*)

Section	Subsection and method	Type of input data	Estimated parameters
B. Estimation of conditional adult survivorship	B.2(d) Paternal orphanhood data from two surveys	Number of respondents with father alive (or dead) classified by five-year age group for two surveys five or 10 years apart Total number of respondents by five-year age group for the same two surveys Number of respondents who did not declare the survivorship status of their father, classified by five-year age group for the same two surveys Number of births occurring in a given year (preferably during the intersurvey period) classified by five-year age group of father (or of mother, if nothing else is available)	The probabilities of surviving from ages 32.5 to ages 45, 50, ..., 90; or the probabilities of surviving from age 37.5 to ages 50, 55, ..., 95 (depending upon the value of *M*, the mean age of fathers at the birth of their children) for males during the intersurvey period
	B.3(b) Widowhood data by age	Number of ever-married male (female) respondents with first spouse alive (or dead) classified by five-year age group Total number of ever-married male (female) respondents by five-year age group Number of ever-married male (female) respondents who did not declare or did not know the survivorship status of first spouse, by five-year age group Singulate mean ages at marriage for both males and females (see annex I)	The probabilities of surviving from age 20 to ages 25, 30, 35, ..., 55 (60) for females (males) The time period to which each estimate refers when mortality is changing
	B.3(c) Widowhood data by duration of first marriage	Number of ever-married male (female) respondents with first spouse alive (or dead) classified by five-year duration-of-marriage group Total number of ever-married male (female) respondents classified by five-year duration-of-marriage group Number of ever-married male (female) respondents who did not declare or did not know the survivorship status of first spouse, by five-year duration group Singulate mean age at marriage for females (males)	Probabilities of surviving from age 20 to ages 25, 30, ..., 50 for females (males) The time period to which each estimate refers when mortality is changing
	B.3(d) Widowhood data from two surveys	Number of ever-married male (female) respondents with spouse alive (or dead) classified by five-year age (duration) group for two surveys five or 10 years apart Total number of ever-married male (female) respondents classified by five-year age (duration) group from the same two surveys Number of ever-married male (female) respondents who did not state the survivorship status of their first spouse classified by five-year age (duration) group for the same two surveys Singulate mean ages at marriage for. males and females for the two surveys	Probability of surviving from age 20 to ages 25, 30, ..., 50 for females (males) during the intersurvey period

TABLE 85 (*continued*)

Section	Subsection and method	Type of input data	Estimated parameters
C. Estimation of survivorship to adulthood from birth	C.2 Maternal orphanhood data	Number of respondents with mother alive (or dead) classified by five-year age group Total number of respondents by five-year age group Number of respondents who did not declare or did not know the survivorship status of their mother classified by five-year age group Number of births in a year classified by five-year age group of mother An estimate of $l(2)$ for females	$l(45), l(50), \ldots, l(75)$ for females
	C.3(b) Widowhood data by age	Number of ever-married male (female) respondents with first spouse alive (or dead) classified by five-year age group Total number of ever-married male (female) respondents by five-year age group Number of ever-married male (female) respondents who did not declare the survivorship status of first spouse, by five-year age group Singulate mean age at marriage for both males and females An estimate of $l(2)$ for females (males)	$l(25), l(30), \ldots, l(55)$ (or $l(60)$) for females (males)
	C.3(c) Widowhood data by duration of first marriage	Number of ever-married male (female) respondents with first spouse alive (or dead) classified by five-year duration-of-marriage group Total number of ever-married male (female) respondents classified by five-year duration group Number of ever-married male (female) respondents who did not declare the survivorship status of first spouse, by five-year duration group Singulate mean age at marriage for females (males) An estimate of $l(2)$ for females (males)	$l(20), l(25), \ldots, l(40)$ for females (males)

and according to the type of data each method requires: information on the orphanhood status; or data on the widowhood status of respondents. The organization of the following sections closely follows this classification. In order to aid the user in selecting the method best suited for a particular application, brief descriptions of each section follow (see also table 85):

Section B. Estimation of conditional adult survivorship. This section presents methods that allow the estimation of conditional probabilities of survivorship, that is, probabilities of surviving to age x given that the target population has already survived to age y, where y is less than x. This section is divided into two main subsections. In the first, methods using data on the orphanhood status of respondents are described; in the second, methods using data on the widowhood status of ever-married respondents are presented;

Section C. Estimation of survivorship to adulthood from birth. This section presents methods that permit the estimation of the probabilities of surviving from birth to certain ages x, all greater than 20. All the methods described require as input an estimate of $l(2)$, the probability of surviving from birth to exact age 2. The two main parts of this section present methods based on orphanhood and widowhood data, respectively.

B. ESTIMATION OF CONDITIONAL ADULT SURVIVORSHIP

1. *General characteristics*

The methods described in this section deal with the estimation of adult mortality from information about the orphanhood or widowhood status of respondents. These methods may be called "conditional" because the estimated parameters are conditional probabilities of survival that do not, by themselves, define a complete life table. To derive life-table values from them more information is needed about child mortality; methods for combining information about child and adult mortality are described in chapter VI.

2. *Estimation of adult survivorship based on proportions not orphaned*

(a) *Basis of method and its rationale*

Data on the proportions of respondents whose mother (father) is still living can yield plausible estimates of adult mortality. The first method of estimation based on this type of data was proposed by Brass,[3] who established an equation relating the female probability of surviving from age 25 to age 25 + n to the proportions of respondents in two contiguous five-year age groups whose mother was still alive at the time of the interview. This equation has the form

$$l(25+n)/l(25)=W(n)S(n-5)+(1-W(n))S(n) \tag{B.1}$$

where $S(n)$ is the proportion of respondents aged from n to $n+4$ with mother alive, and $W(n)$ is a weighting factor employed to make allowance for typical age patterns of fertility and mortality. The set of $W(n)$ values that Brass proposed was estimated on the basis of data simulated by using a single mortality pattern (the African standard) and model fertility schedules of fixed shape but variable age locations. Each age location of the fertility schedule is associated with a particular value of M, the mean age of women (or men) at the birth of their children. Thus, the weights, $W(n)$, depend both upon n, the central point of the age groups being considered, and upon M.

More recently, Hill and Trussell[4] proposed another estimation procedure based on the following equation:

$$l(25+n)/l(25)=a(n)+b(n)M+c(n)S(n-5) \tag{B.2}$$

where $a(n)$, $b(n)$ and $c(n)$ are coefficients estimated by using linear regression to fit equation (B.2) to data from 900 simulated cases. These cases were derived by using several fertility schedules generated by the Coale-Trussell[5] model and a variety of mortality schedules generated by the logit system[6] with the four different Coale-Demeny[7] mortality patterns as standards (see chapter I, subsections B.2 and B.4).

When both methods of estimation were applied to nearly 1,000 other cases simulated by using different fertility and mortality schedules, the method proposed by Brass was found to perform as well as or better than the regression method for n not exceeding 30 years, while the regression method produced substantially better results for higher values of n.

Even though this comparison was carried out only on simulated cases that are not subject to the type of errors commonly found in real data, it does reveal the probable strengths and weaknesses of the different methods. Since these methods seem to complement each other in the realm of theory, both of them are described here in the hope that they may also complement each other in practice.

Before proceeding with their description, some general features of methods that attempt the estimation of adult mortality based on the reported proportions of orphaned respondents by age and an indicator of the age pattern of fertility should be pointed out.

First, the estimated probabilities of survivorship do not refer to the entire population, since they reflect only the mortality experience of parents with surviving children. Furthermore, if questions on orphanhood are asked of the entire population, parents with several surviving children will tend to be overrepresented. Theoretically, this problem can be avoided by using an additional filter question that seeks to identify only one child per parent, such as the oldest surviving child or the first-born child. However, in practice, errors in the reporting of family-order status have been found to be so large that methods of analysis using data where the responses have been limited to one child per parent have not yielded better estimates than the original methods.[8]

Secondly, survivorship estimates based on reports by young respondents, and thus corresponding to small values of n (under 20), tend to be affected by misreporting of orphanhood status: young orphaned children are often adopted by relatives who report them as their own children. This phenomenon artificially inflates the proportion of young respondents having a surviving parent and biases upward the estimated survivorship probabilities of younger adults.

Lastly, the estimated probabilities of survival do not, strictly speaking, refer to specific time periods, since they represent average measures over the somewhat ill-defined intervals of exposure to the risk of dying of the target population. In cases where mortality has remained essentially constant, problems in the interpre-

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[3] W. Brass and K. H. Hill, "Estimating adult mortality from orphanhood", *Proceedings of the International Population Conference, Liège, 1973* (Liège, International Union for the Scientific Study of Population, 1973), vol. 3, pp. 111-123.

[4] K. Hill and J. Trussell, "Further developments in indirect mortality estimation", *Population Studies*, vol. XXXI, No. 2 (July, 1977), pp. 313-333.

[5] Ansley J. Coale and T. James Trussell, "Model fertility schedules: variations in the age structure of childbearing in human populations", *Population Index*, vol. 40, No. 2 (April 1974), pp. 185-258.

[6] William Brass, *Methods for Estimating Fertility and Mortality from Limited and Defective Data* (Chapel Hill, North Carolina, Carolina Population Center, Laboratories for Population Statistics, 1975).

[7] Ansley J. Coale and Paul Demeny, *Regional Model Life Tables and Stable Populations* (Princeton, New Jersey, Princeton University Press, 1966).

[8] Kenneth Hill, Hugo Behm and Augusto Soliz, *La situación de la mortalidad en Bolivia* (La Paz, Instituto Nacional de Estadística, 1976).

tation of the estimates obtained do not arise since, in the absence of data errors, they should all imply the same, unchanging mortality level. However, because mortality has not remained constant during the recent past in most countries, the interpretation of survivorship probabilities derived from orphanhood data is not always straightforward. Interpretation and assessment are easier when the estimates obtained can be related to specific time periods. If one can assume that mortality has been changing regularly (for instance, by assuming that in the logit system the parameter indicating mortality level, α, has been changing linearly with respect to time) and that the adult mortality pattern of the target population is similar to that represented by the general standard (see chapter I, subsection B.4), it is possible to estimate the time t (as number of years before the survey) to which each survivorship probability refers. The estimation method used for this purpose has only recently been proposed by Brass and Bamgboye;[9] and although it has not yet been widely tested, its general relevance warrants its inclusion in this chapter.

(b) *Brass method*

(i) *Data required*

The following data are required for this method:

(*a*) The proportion of respondents with a surviving mother (father) in each five-year age group from n to $n+4$. This proportion is denoted by $S(n)$. The set of proportions $S(n)$ can be calculated when any two of the following items are available: (*a*) the number of respondents with mother (father) alive; (*b*) the number of respondents with mother (father) dead; (*c*) the total number of respondents whose mother's (father's) survival status is known. It is important to exclude from the calculations all respondents who did not know or did not declare their mother's (father's) survival status. In every case, data must be classified by five-year age group;

(*b*) The number of births in a given year classified by five-year age group of mother (father). This information is needed to estimate M, the mean age of mothers (fathers) at the birth of their children in the population being studied. The M to be estimated is not the mean age of the fertility schedule (also known as "mean age of childbearing"); it is, rather, a mean age of the fertility schedule weighted by the age distribution of the female (male) population. It may be regarded as an estimate of the average age difference between mother (father) and child in the population, thus being an indicator of the average age at which the target persons (parents) begin their exposure to the risk of dying.

(ii) *Computational procedure*

The steps of the computational procedure are described below.

Step 1: calculation of mean age at maternity (paternity). The mean age of mothers (fathers) at the birth of a group of children (normally those born in the year before the survey) is denoted by M. If one uses the index i to denote the different five-year age groups in the reproductive life span of a woman and lets $B(i)$ be the number of births during a particular period to women in age group i, then

$$M = \sum_{i=1}^{7} a(i)B(i) / \sum_{i=1}^{7} B(i) \qquad \text{(B.3)}$$

where $a(i)$ is the mid-point of age group i. (The user should be reminded that, just as stated in chapters II and III, $i = 1$ represents age group 15-19, $i = 2$ is 20-24 and so on.) Note that if the births used to calculate M are those reported as occurring during the year preceding the survey and are tabulated by age of mother at the time of the survey, the true age group of the mother will be, on average, six months younger than stated, so that six months should be subtracted from the mid-point of each age group when calculating M.

The estimation of M for males is one of the additional problems associated with the estimation of male adult mortality from the proportions of respondents with a surviving father. Fertility questions are generally not asked of males, so the information from which the female M is estimated is usually not available for fathers. Births during the year preceding a survey are sometimes tabulated by age of husband, but this tabulation is generally limited to those cases in which the mother and her husband are enumerated in the same household. Calculating the male M from such a tabulation often biases its value upward because young fathers are more likely to be temporarily absent.

A more robust procedure for estimating M for males consists of adjusting the female M by using information on marital status. The median age of the currently married population can be calculated by sex, and the difference between the male and female medians can be added to the previously calculated female M to obtain an estimate of the male M. Medians are used to reduce the influence of older and, for the purpose in hand, largely irrelevant couples. In principle, the assumption of constant fertility can be relaxed by employing different values of M for different age groups of respondents, but in practice the data required to follow this approach are often lacking.

Step 2: calculation of weighting factors. For the value of M calculated above and for each value of n, the weighting factors, $W(n)$, are calculated by interpolating linearly (see annex IV) in table 86 (table 87 is used when fathers are being considered).

Step 3: calculation of survivorship probabilities. If the survivorship of mothers is being considered, the probabilities of surviving from age 25 to age 25 + n are calculated by using the equation

$$l_f(25+n)/l_f(25) = W(n)S(n-5) + (1.0 - W(n))S(n) \qquad \text{(B.4)}$$

where $S(n)$ is the proportion of respondents aged from n to $n+4$ who declared that their mothers were alive at the time of the interview.

[9] W. Brass and E. A. Bamgboye, *op. cit.*

TABLE 86. WEIGHTING FACTORS, $W(n)$, FOR CONVERSION OF PROPORTIONS OF RESPONDENTS WITH MOTHER ALIVE INTO SURVIVORSHIP PROBABILITIES FOR FEMALES

Age n (1)	*Mean age, M, for mothers at maternity* 22 (2)	23 (3)	24 (4)	25 (5)	26 (6)	27 (7)	28 (8)	29 (9)	30 (10)
10..............	0.420	0.470	0.517	0.557	0.596	0.634	0.674	0.717	0.758
15..............	0.418	0.489	0.556	0.618	0.678	0.738	0.800	0.863	0.924
20..............	0.404	0.500	0.590	0.673	0.756	0.838	0.921	1.004	1.085
25..............	0.366	0.485	0.598	0.704	0.809	0.913	1.016	1.118	1.218
30..............	0.303	0.445	0.580	0.708	0.834	0.957	1.080	1.203	1.323
35..............	0.241	0.401	0.554	0.701	0.844	0.986	1.128	1.270	1.412
40..............	0.125	0.299	0.467	0.630	0.791	0.950	1.111	1.274	1.442
45..............	0.007	0.186	0.361	0.535	0.708	0.884	1.063	1.250	1.447
50..............	−0.190	−0.017	0.158	0.334	0.514	0.699	0.890	1.095	1.318
55..............	−0.368	−0.220	−0.059	0.101	0.270	0.456	0.645	0.856	1.083
60..............	0.466	−0.352	−0.217	−0.084	0.053	0.220	0.378	0.579	0.800

Estimation equation:

$$l_f(25+n)/l_f(25) = W(n)\,S(n-5) + (1-W(n))\,S(n)$$

TABLE 87. WEIGHTING FACTORS, $W(n)$, FOR CONVERSION OF PROPORTIONS OF RESPONDENTS WITH FATHER ALIVE INTO SURVIVORSHIP PROBABILITIES FOR MALES

Age n (1)	*Mean age, M, for fathers at paternity* 28 (2)	29 (3)	30 (4)	31 (5)	32 (6)	33 (7)	34 (8)	35 (9)	36 (10)
				(a) *From 32.5 years*					
10..............	0.192	0.258	0.322	0.388	0.455	0.521	0.587	0.650	0.714
15..............	0.151	0.243	0.336	0.429	0.522	0.613	0.702	0.790	0.877
20..............	0.043	0.166	0.287	0.406	0.523	0.638	0.750	0.861	0.969
25..............	−0.093	0.051	0.194	0.335	0.474	0.611	0.744	0.877	1.007
30..............	−0.327	−0.161	0.001	0.162	0.319	0.475	0.627	0.779	0.931
35..............	−0.640	−0.408	−0.211	−0.047	0.109	0.269	0.438	0.610	0.782
40..............	−0.856	−0.714	−0.554	−0.379	−0.203	−0.034	0.133	0.303	0.480
45..............	−1.120	−0.963	−0.806	−0.651	−0.495	−0.340	−0.183	−0.024	0.141
50..............	−1.162	−1.030	−0.903	−0.776	−0.651	−0.524	−0.396	−0.264	−0.128
55..............	−1.040	−0.943	−0.850	−0.758	−0.667	−0.576	−0.486	−0.397	−0.304

Estimation equation:

$$l_m(35+n)/l_m(32.5) = W(n)\,S(n-5) + (1.0-W(n))\,S(n)$$

(b) *From 37.5 years*

	36	37	38	39	40	41	42	43	44
10..............	0.384	0.460	0.537	0.613	0.687	0.758	0.827	0.897	0.969
15..............	0.378	0.484	0.588	0.690	0.790	0.888	0.984	1.079	1.174
20..............	0.324	0.455	0.582	0.708	0.833	0.954	1.075	1.195	1.318
25..............	0.164	0.315	0.465	0.613	0.759	0.904	1.051	1.197	1.346
30..............	−0.043	0.122	0.286	0.450	0.614	0.778	0.944	1.116	1.295
35..............	−0.359	−0.183	−0.015	0.152	0.321	0.496	0.677	0.863	1.062
40..............	−0.624	−0.473	−0.316	−0.157	0.003	0.168	0.342	0.529	0.722
45..............	−0.757	−0.631	−0.503	−0.372	−0.237	−0.099	0.047	0.208	0.393
50..............	−0.742	−0.650	−0.559	−0.471	−0.377	−0.280	−0.182	−0.069	0.063
55..............	−0.559	−0.541	−0.485	−0.425	−0.366	−0.308	−0.238	−0.149	−0.049

Estimation equation:

$$l_m(40+n)/l_m(37.5) = W(n)\,S(n-5) + (1.0-W(n))\,S(n)$$

In the case of fathers, the value 25 is replaced by the values 32.5 or 37.5 to allow for the fact that men are usually older than women at the birth of their children. The survivorship probabilities are estimated in this case by the following equations:

$$l_m(35+n)/l_m(32.5) = W(n)S(n-5)+(1.0-W(n))S(n) \quad \text{(B.5)}$$

if the weighting factors $W(n)$ are obtained from table 87, part (a); and

$$l_m(40+n)/l_m(37.5) = W(n)S(n-5)+(1.0-W(n))S(n) \quad \text{(B.6)}$$

if the weighting factors are obtained from table 87, part

TABLE 88. VALUES OF THE STANDARD FUNCTION FOR CALCULATION OF THE TIME REFERENCE FOR INDIRECT ESTIMATES OF ADULT SURVIVORSHIP

Age x (1)	Standard function $Z(x)$ (2)	Age x (3)	Standard function $Z(x)$ (4)	Age x (5)	Standard function $Z(x)$ (6)	Age x (7)	Standard function $Z(x)$ (8)	Age x (9)	Standard function $Z(x)$ (10)
26	0.090	36	0.092	46	0.149	56	0.274	66	0.452
27	0.090	37	0.093	47	0.160	57	0.289	67	0.473
28	0.090	38	0.095	48	0.171	58	0.305	68	0.495
29	0.090	39	0.099	49	0.182	59	0.321	69	0.518
30	0.090	40	0.104	50	0.193	60	0.338	70	0.542
31	0.090	41	0.109	51	0.205	61	0.356	71	0.568
32	0.090	42	0.115	52	0.218	62	0.374	72	0.595
33	0.090	43	0.122	53	0.231	63	0.392	73	0.622
34	0.090	44	0.130	54	0.245	64	0.411	74	0.650
35	0.091	45	0.139	55	0.259	65	0.431	75	0.678

(b). In both cases, $S(n)$ stands for the proportion of respondents in the age group from n to $n+4$ whose father was alive at the time of the interview. A decision has to be made whether to use the weights given in table 87, part (a), and hence equation (B.5); or those in table 87, part (b), and hence equation (B.6). In general, the choice depends upon the estimated value of M: if it is less than or equal to 36, part (a) should be used; if it is greater than 36, part (b) should be used.

Step 4: calculation of number of years before the survey to which the survivorship estimates refer. It can be shown that if the level of mortality is declining linearly on the logit scale (see chapter I, subsection B.4), the survivorship estimates obtained from orphanhood data are equal to those prevalent at specific time periods prior to the survey and that the time location of these periods is largely independent of the rate of the mortality change.[10] In addition, when female mortality in adulthood has a pattern similar to that embodied by the general standard (see chapter I, subsection B.4), the number of years before the survey to which each estimate derived from maternal orphanhood data refers, denoted by $t(n)$, can be estimated as

$$t(n) = n(1.0 - u(n))/2.0 \qquad \text{(B.7)}$$

where

$$u(n) = 0.3333 \ln({}_{10}S_{n-5}) + Z(M+n) + 0.0037(27-M), \qquad \text{(B.8)}$$

and the value of $Z(M+n)$ is obtained by interpolating linearly in table 88.

Note that in this case ${}_{10}S_{n-5}$ represents the proportion of respondents in the age group from $n-5$ to $n+4$ with mother alive, and that n is the mid-point of the 10-year age group being considered.

When data on paternal orphanhood are being used, equations (B.7) and (B.8) become

$$t(n) = (n+0.75)(1.0 - u(n))/2.0 \qquad \text{(B.9)}$$

and

$$u(n) = 0.3333 \ln({}_{10}S_{n-5}) + Z(M+n) + 0.0037(27 - M + 0.75) \qquad \text{(B.10)}$$

where $Z(x)$ is still obtained from table 88; ${}_{10}S_{n-5}$ now represents the proportion of respondents aged from $n-5$ to $n+4$ with father alive; M is the mean age of fathers at the time of their children's birth; n is the mid-point of the age group considered; and 0.75 or three quarters of a year have been added to make allowance for the fact that a father must have been alive at the time of conception, but not necessarily at the time of the birth of his offspring.

(iii) *A detailed example*

The data shown in tables 89 and 90 were collected by the National Demographic Survey carried out in Bolivia during 1975.[11] They are used here to illustrate the way in which the estimation of female adult mortality is carried out using data on the maternal orphanhood status of respondents.

Table 89 shows both the raw data gathered by the survey and the proportions of respondents whose mother was alive at the time of the interview. Note that in calcu-

TABLE 89. DATA ON MATERNAL ORPHANHOOD STATUS AND PROPORTIONS OF RESPONDENTS WITH MOTHER ALIVE, BOLIVIA, 1975

Age group of respondent (1)	Number of respondents with: Mother alive (2)	Mother dead (3)	Unknown maternal orphanhood status (4)	Proportion with mother alive $S(n)$ (5)
15-19	5 540	448	6	0.9252
20-24	3 995	541	10	0.8807
25-29	2 886	769	8	0.7896
30-34	1 910	852	9	0.6915
35-39	1 661	1 234	11	0.5737
40-44	1 027	1 272	7	0.4467
45-49	855	1 556	6	0.3546
50-54	369	1 243	6	0.2289

[10] *Ibid.*

[11] K. Hill, H. Behm and A. Soliz, *op. cit.*

TABLE 90. CHILDREN BORN DURING THE 12 MONTHS PRECEDING THE SURVEY, BY AGE OF MOTHER AT TIME OF THE SURVEY, BOLIVIA, 1975

Age group of mother at time of interview (1)	*Index* i (2)	*Mid-point of age group (adjusted by six months)* $a(i)$ (3)	*Number of children born in past year* $B(i)$ (4)
15-19	1	17	136
20-24	2	22	409
25-29	3	27	485
30-34	4	32	320
35-39	5	37	259
40-44	6	42	94
45-49	7	47	50
TOTAL			753

lating the latter figure, the numbers of respondents who were classified in the category of "unknown maternal orphanhood status" were ignored. In the case of the 1975 survey in Bolivia, the numbers in the unknown category are very small and their inclusion in the denominators of the proportions with surviving mother would not have affected the final results. However, because greater levels of non-response may occur, it is important to exclude the non-responses when calculating the proportions with surviving mother. As an example, $S(50)$ is computed explicitly below:

$$S(50) = 369/(369+1{,}243) = 0.2289.$$

The computational procedure is described below.

Step 1: calculation of mean age at maternity. According to equation (B.3):

$$M = \sum_{i=1}^{7} a(i)B(i) / \sum_{i=1}^{7} B(i)$$

where $a(i)$ is the mid-point of age group i; and $B(i)$ is the number of births to women in age group i. However, to obtain a correct estimate of the mean age at maternity, M, the births used in equation (B.3) should be classified by age of mother at the time the birth occurred. In the present case, the age reported by a woman is that at the time of the interview and not that at the time of the birth; some allowance must be made for this fact. The simplest strategy is to assume that births are uniformly distributed in time and with respect to mother's age. Hence, on average, women were six months younger at the time of the birth they reported than at the time of the interview, so that, for example, the current age group spanning exact ages 15-20 may be considered to span exact ages from 14.5 to 19.5 at the time the births occurred. All subsequent age groups are similarly affected. Therefore, the central $a(i)$ values to be used in applying equation (B.3) are 17 instead of 17.5, 22 instead of 22.5, and so on, as shown in column (3) of table 90.

Applying equation (B.3), M is calculated as follows:

$$\sum_{i=1}^{7} a(i)B(i) = (17)(136) + (22)(409) + \cdots +$$

$$(47)(50) = 50{,}526$$

and

$$\sum_{i=1}^{7} B(i) = 1{,}753$$

so

$$M = 50{,}526/1{,}753 = 28.8.$$

Step 2: calculation of weighting factors. Since data on maternal orphanhood are being considered, the appropriate weights, $W(n)$, are obtained by interpolating linearly (see annex IV) between the values given in table 86. The value of M is 28.8 years, so the weights in the columns labelled "28" and "29" are used as extremes in the interpolation. For all values of n, the interpolation factor Θ is

$$\Theta = (29-28.8)/(29-28) = 0.2.$$

Therefore, to obtain $W(35)$, for example, the values for $n = 35$ appearing under the columns for M equal to 28 and 29 of table 86 are weighted by Θ and $(1-\Theta)$, respectively, yielding

$$W(35) = 0.2(1.128) + 0.8(1.270) = 1.2416.$$

The complete set of $W(n)$ values corresponding to $M = 28.8$ is shown in column (2) of table 91.

Step 3: calculation of survivorship probabilities. Once the weighting factors corresponding to the observed M have been calculated, the values of $l_f(25+n)/l_f(25)$ are

TABLE 91. ESTIMATION OF FEMALE ADULT SURVIVORSHIP FROM PROPORTIONS OF RESPONDENTS WITH SURVIVING MOTHER, USING THE BRASS METHOD, BOLIVIA, 1975

Age n (1)	*Weighting factor* $W(n)$ (2)	*Proportion with mother surviving* $S(n-5)$ (3)	*Complement of weighting factor* $(1-W(n))$ (4)	*Proportion with mother surviving* $S(n)$ (5)	*Female adult survivorship probability* $l_f(25+n)/l_f(25)$ (6)	*West mortality level* (7)
20.............	0.9874	0.9252	0.0126	0.8807	0.925	18.4
25.............	1.0976	0.8807	−0.0976	0.7896	0.890	18.1
30.............	1.1784	0.7896	−0.1784	0.6915	0.807	16.0
35.............	1.2416	0.6915	−0.2416	0.5737	0.720	15.0
40.............	1.2414	0.5737	−0.2414	0.4467	0.604	13.9
45.............	1.2126	0.4467	−0.2126	0.3546	0.466	13.0
50.............	1.0540	0.3546	−0.0540	0.2289	0.361	14.3

computed as indicated by equation (B.4). Table 91 summarizes these computations. This table also shows the mortality level in the Coale-Demeny West family of model life tables associated with each survivorship ratio. These levels were calculated by interpolating linearly between the values given in table 210 (see annex VI). They provide a useful index for examining the consistency of the survivorship ratios themselves.

As an example, the calculation of the level consistent with the estimated $l_f(65)/l_f(25)$ is carried out below in detail. The value of $l_f(65)/l_f(25)$ according to table 91 is 0.604. The column labelled "65" of table 210 in annex VI is then used to locate the two values that bracket the estimated value. They are 0.58183, corresponding to level 13; and 0.60583, corresponding to level 14. Hence, the interpolation factor Θ is

$$\Theta = (0.60400-0.58183)/(0.60583-0.58183) = 0.92$$

and the estimated level is

$$(0.92)(14)+(0.08)(13) = 13.92.$$

The complete set of mortality levels is shown in column (7) of table 91.

Step 4: calculation of number of years before the survey to which the survivorship estimates refer. The reference period of each of the estimates obtained in the previous step, denoted by $t(n)$, is calculated from ${}_{10}S_{n-5}$, the proportion of respondents aged from $n-5$ to $n+4$ whose mother was alive at the time of the interview. These proportions are calculated by dividing the number of respondents with surviving mother in the two adjacent age groups from $n-5$ to $n-1$ and from n to $n+4$ by the sum of the number of respondents in both age groups who provided information on mother's survival. For example,

$${}_{10}S_{20} = (3{,}995+2{,}886)/(3{,}995+2{,}886+541+769) = 0.8401.$$

The complete set of ${}_{10}S_{n-5}$ values is shown in column (2) of table 92.

Because the data at hand refer to maternal orphanhood, equations (B.7) and (B.8) are used in calculating $t(n)$. In step 1, M was found to be equal to 28.8 years. Therefore, the values of $x = M+n$ range from 48.8 to 78.8, increasing in steps of five years. The standard function, $Z(x)$, for calculation of the reference period, is obtained for these values by linear interpolation within table 88. Note that because the table does not cover the range 78-79, the last Z value calculated is $Z(73.8)$. Thus, $Z(53.8)$ is obtained as

$$Z(53.8) = 0.2Z(53)+0.8Z(54) = 0.2(0.231)+0.8(0.245) = 0.242.$$

All $Z(x)$ values are given in column (4) of table 92. Using these values and substituting those of ${}_{10}S_{n-5}$, M and n in equation (B.8), one obtains the set of values for the correction function, $u(n)$, given in column (5) of the same table. To illustrate the procedure followed, $u(30)$ is calculated below:

$$u(30) = 0.3333 \ln {}_{10}S_{25} + Z(58.8) + 0.0037(-1.8)$$
$$= 0.3333 \ln(0.7474) + 0.318 - 0.0067$$
$$= 0.2143.$$

Then, using equation (B.7), $t(n)$ is calculated for each case. Continuing with the illustration of the case $n=30$,

$$t(30) = 30(1-0.2143)/2 = 11.8.$$

The survey in Bolivia was carried out between 15 June and 31 October 1975, so the mid-point of that period may be considered its reference date. The simplest way of obtaining the decimal equivalent of the mid-period date is by transforming the end-points into decimal equivalents and finding their mean. Thus, 15 June 1975, is equivalent to 1975.45 (the number of days from 1 January to 15 June, both included, being 166, and 166/365 = 0.45) and 31 October 1975 is equivalent to 1975.83, so that the desired mean is 1975.64. Therefore, the $l_f(55)/l_f(25)$ estimate listed in table 91 refers approximately to 11.8 years before 1975.6, that is, to 1963.8. The complete set of reference dates and the West mortality levels associated with them are shown in columns (7) and (8), respectively, of table 92.

TABLE 92. ESTIMATION OF TIME REFERENCE PERIODS FOR SURVIVORSHIP ESTIMATES DERIVED FROM MATERNAL ORPHANHOOD DATA, BOLIVIA, 1975

Age n *(1)*	*Proportion with mother surviving* ${}_{10}S_{n-5}$ *(2)*	*Length of exposure indicator* $M+n$ *(3)*	*Standard function* $Z(M+n)$ *(4)*	*Correction function* $u(n)$ *(5)*	*Reference period*[a] $t(n)$ *(6)*	*Reference date (7)*	*West mortality level (8)*
20	0.9060	48.8	0.180	0.1405	8.6	1967.0	18.4
25	0.8401	53.8	0.242	0.1773	10.3	1965.3	18.1
30	0.7474	58.8	0.318	0.2143	11.8	1963.8	16.9
35	0.6313	63.8	0.407	0.2471	13.2	1962.4	15.0
40	0.5175	68.8	0.513	0.2868	14.3	1961.3	13.9
45	0.3996	73.8	0.644	0.3316	15.0	1960.6	13.0

[a] Number of years prior to the survey to which survivorship estimates refer.

It is worth mentioning that the estimates obtained from maternal orphanhood data refer, when adult mortality has been changing steadily, to periods between 8 and 15 years prior to the survey. When judged with respect to these estimated dates, the mortality levels obtained in the previous step seem less satisfactory than at first sight. The estimates imply that female adult mortality in Bolivia fell by an average of one mortality level per annum during the period 1960-1965. It is difficult to believe that such rapid gains in life expectancy could actually have taken place. Further, the similarity of the levels corresponding to the two most recent periods is suspect. It suggests that even up to age groups 20-24 and 25-29 the adoption effect may be biasing the survivorship estimates upward. To what extent such an effect is also operating at ages 30-34 and 35-39 is difficult to ascertain, but the possibility that the estimates for 1962-1964 may also be subject to an undesirable positive bias must be borne in mind. From these brief comments it transpires that the data for Bolivia may not be as consistent as one would desire, and that further analysis and additional, independent evidence may be necessary to establish with a greater degree of certainty the mortality levels to which the female population of Bolivia has been subject.

(c) *Method based on an equation fitted by using regression*

(i) *Data required*

The data required to apply this method in the case of maternal orphanhood are exactly the same as those needed for the Brass method (see subsection B.2 (b) (i); however, no regression method has been developed for the estimation of male mortality from data on paternal orphanhood. The data required are:

(*a*) The proportion of respondents whose mother was alive at the time of the interview, classified by five-year age group. The reported proportion in the age group from n to $n+4$ is denoted by $S(n)$;

(*b*) The number of children born during a given year, classified by five-year age group of mother. These data allow the estimation of M, the mean age of mothers at the birth of a particular group of children.

(ii) *Computational procedure*

The following steps are required in the computational procedure.

Step 1: calculation of mean age at maternity. This step is identical to that described in subsection B.2 (b) (ii). It is not described again here.

Step 2: calculation of survivorship probabilities. Using the values of the coefficients $a(n)$, $b(n)$ and $c(n)$ shown in table 93, female survivorship probabilities are obtained by substituting these values in the following equation:

$$l_f(25+n)/l_f(25) = a(n)+b(n)M+c(n)S(n-5) \tag{B.11}$$

where M is the mean age of mothers at the birth of their children; and $S(n-5)$ is the proportion of respondents in the age group from $n-5$ to $n-1$ whose mother was alive at the time of the interview.

TABLE 93. COEFFICIENTS FOR ESTIMATION OF FEMALE SURVIVORSHIP PROBABILITIES FROM AGE 25 FROM PROPORTIONS WITH SURVIVING MOTHER

Age n (1)	Coefficients: $a(n)$ (2)	$b(n)$ (3)	$c(n)$ (4)
20.............	−0.1798	0.00476	1.0505
25.............	−0.2267	0.00737	1.0291
30.............	−0.3108	0.01072	1.0287
35.............	−0.4259	0.01473	1.0473
40.............	−0.5566	0.01903	1.0818
45.............	−0.6676	0.02256	1.1228
50.............	−0.6981	0.02344	1.1454

Estimation equation:
$l_f(25+n)/l_f(25) = a(n)+b(n)M+c(n)S(n-5)$

Note should be taken that this method permits the estimation of female survivorship only. No regression method has been developed to estimate male survivorship, so if paternal orphanhood data are available, the original Brass method has to be used.

It should also be pointed out that the conditional probabilities of survivorship obtained by using this method do not, by themselves, define a complete life table, unless one can assume that the mortality pattern of the population studied is identical to that of some model set of life tables. When information on child mortality is available, the techniques described in chapter VI can be used to construct a life table that does not depend upon such a restrictive assumption.

Step 3: calculation of number of years before the survey to which the survivorship estimates refer. In cases where adult mortality has been changing regularly during the 15 or 20 years preceding the survey (that is, the change has been linear on the logit scale), estimates of the time to which each of the survivorship probabilities obtained in the previous step refers, denoted by $t(n)$, can be calculated by means of the following equations:

$$u(n) = 0.3333 \ln S(n-5) + Z(M+n-2.5) + 0.0037(27-M) \tag{B.12}$$

and

$$t(n) = (n-2.5)(1.0-u(n))/2.0 \tag{B.13}$$

where $S(n-5)$ is the proportion of respondents aged from $M-5$ to $M-1$ whose mother was alive at the time of the survey; M is the mean age of mothers at the time of the birth of their children; $n-2.5$ is a rough indicator of the mean age of respondents; and $Z(x)$ is a standard function of age whose values in any given case can be obtained by interpolating between the values listed in table 88. Strictly speaking, the estimates yielded by equations (B.12) and (B.13) when the $Z(x)$ values of table 88 are used as input are based on the assumption that female adult mortality in the population being studied has a similar pattern to that embodied by the general standard (see chapter I, subsection B.4). In practice, however, the impact of deviations from this assumption is unlikely to be large, at least in comparison with the effects on the final estimates of deviations from the assumed linear trend followed by adult mortality changes over time.

(iii) *A detailed example*

The application of the regression method is illustrated below by again using the data for Bolivia presented in subsection B.2 (b) (iii) (see table 89).

Step 1: calculation of mean age at maternity. Refer to step 1 of subsection B.2 (b) (iii), where the mean age of mothers at maternity, M, was estimated as 28.8 years for Bolivian women.

Step 2: calculation of survivorship probabilities. Table 94 summarizes the calculations needed to estimate these probabilities. It shows that the application of equation (B.11) is straightforward and that the estimation process is very simple. Once again, the mortality level consistent with each survivorship ratio in the West family of model life tables has been computed by interpolating in table 210 in annex VI (see step 3 of subsection B.2 (b) (iii)). Note that for a value of n under 40, the survivorship estimates obtained by this method are very similar to those obtained by the Brass procedure (see table 91). For values of n of 40 and over, however, the differences increase with n; for these ages, the regression-based estimates would probably be preferable.

Step 3: calculation of number of years before the survey to which the survivorship estimates refer. As stated by equations (B.12) and (B.13), the values of this reference period, denoted by $t(n)$, depend in this case upon the observed proportions not orphaned in each five-year age group, $S(n-5)$. They are shown in column (2) of table 95. The values of $Z(x)$ for x ranging from 46.3 to 76.3 in steps of five years are obtained by interpolating linearly between the values listed in table 88. For example, $Z(66.3)$ is obtained as

$$Z(66.3) = 0.7Z(66) + 0.3Z(67) =$$

$$0.7(0.452) + 0.3(0.473) = 0.458.$$

Since the values listed in table 88 do not cover the age range from 76 to 77, linear extrapolation was used to calculate $Z(76.3)$. The complete set of $Z(x)$ values is shown in column (4) of table 95. Using equation (B.12) and these values as input, the set of $u(n)$ values can be calculated. For example,

$$u(40) = 0.3333 \ln S(35) + Z(66.3) + 0.0037(27.0 - 28.8)$$

$$= 0.3333 \ln (0.5737) + 0.458 - 0.0067$$

$$= 0.2661,$$

so that

$$t(40) = (37.5)(1.0 - 0.2661)/2.0 = 13.8.$$

The complete set of $t(n)$ values, the number of years prior to the survey to which each survivorship estimate refers, is shown in column (6) of table 95. Since the survey reference date is 1975.6, these $t(n)$ estimates can be transformed to dates by subtraction, the results being shown in column (7) of table 95. The West mortality levels implied by each survivorship estimate are also shown

TABLE 94. CALCULATION OF FEMALE SURVIVORSHIP PROBABILITIES FROM AGE 25 USING PROPORTIONS WITH SURVIVING MOTHERS AND THE REGRESSION METHOD, BOLIVIA, 1975

Age n (1)	Intermediate value $a(n) + b(n)(28.8)$ (2)	Coefficient $c(n)$ (3)	Proportion with mother surviving $S(n-5)$ (4)	Female adult survivorship probability $l_f(25+n)/l_f(25)$ (5)	West mortality level (6)
20.............	−0.0427	1.0505	0.9252	0.929	18.7
25.............	−0.0144	1.0291	0.8807	0.892	18.2
30.............	−0.0021	1.0287	0.7896	0.810	16.2
35.............	−0.0017	1.0473	0.6915	0.722	15.1
40.............	−0.0085	1.0818	0.5737	0.612	14.2
45.............	−0.0179	1.1228	0.4467	0.484	13.7
50.............	−0.0230	1.1454	0.3546	0.383	15.3

TABLE 95. ESTIMATION OF TIME REFERENCE PERIODS FOR SURVIVORSHIP PROBABILITIES DERIVED FROM MATERNAL ORPHANHOOD DATA USING THE REGRESSION METHOD, BOLIVIA, 1975

Age n (1)	Proportion with mother surviving $S(n-5)$ (2)	Length of exposure indicator $M+n-2.5$ (3)	Standard function $Z(M+n-2.5)$ (4)	Correction function $u(n)$ (5)	Reference period[a] $t(n)$ (6)	Reference date (7)	West mortality level (8)
20.............	0.9252	46.3	0.152	0.1194	7.7	1967.9	18.7
25.............	0.8807	51.3	0.209	0.1600	9.5	1966.1	18.2
30.............	0.7896	56.3	0.279	0.1936	11.1	1964.5	16.2
35.............	0.6915	61.3	0.361	0.2314	12.5	1963.1	15.1
40.............	0.5737	66.3	0.458	0.2661	13.8	1961.8	14.2
45.............	0.4467	71.3	0.576	0.3007	14.9	1960.7	13.7
50.............	0.3546	76.3	0.714	0.3618	15.2	1960.4	15.3

[a] Number of years prior to the survey to which survivorship estimates refer.

in table 95 to facilitate comparisons and assessment. Note that, as already pointed out in subsection B.2 (b) (iii), the pace of the mortality change implied by these estimates between 1960 and 1966 seems implausibly rapid. It is also clear that the relatively low mortality associated with values of n of 20, 25 and 50 are suspect, that for 50 because it does not conform with the trend of the rest, and those for 20 and 25 because they imply a fairly important decline in mortality from mid-1964 to 1966, compared with a very moderate decline in previous years. It is very likely that the survivorship estimates for n values of 20 and 25 are biased upward by the adoption effect and that the survivorship ratio for n of 50 is distorted both by overreporting of age and by misreporting of maternal survival.

(d) *Use of data from two surveys*

One of the problems faced when estimating adult survivorship probabilities from data on the survival of parents is that if mortality has been changing, the estimates refer to some fairly distant point in the past. If, however, information of orphanhood has been collected by two censuses or surveys and the period between them is a multiple of five years, cohorts from the first census can be identified at the second, and survivorship probabilities applicable to the intersurvey period can be estimated from the constructed proportions not orphaned for a hypothetical intersurvey cohort of respondents. It is assumed, of course, that migration does not affect either set of proportions not orphaned and that no relationship exists between the mortality of the respondents and that of their mothers. If the period between the two surveys is not a multiple of five years, a set of proportions not orphaned for a suitable point in time can, in some circumstances, be estimated by interpolation between or extrapolation beyond the observed sets.

(i) *Data required*

The following data are required for this method:

(*a*) The proportion of respondents with surviving mother in each five-year age group from n to $n+4$ for two points five or 10 years apart, denoted by $S(n, 1)$ for the first survey and $S(n, 2)$ for the second;

(*b*) The number of births in a year classified by five-year age group of mother from one of the surveys (and preferably from both) or for some year in the intersurvey period.

(ii) *Computational procedure*

The steps of the computational procedure are given below.

Step 1: calculation of mean age at maternity. See the description of step 1 given in subsection B.2 (b) (ii). If the data required for the calculation of the mean age, M, are available from both surveys, M can be calculated for both, and the average can be used in the analysis. If the required data are available for only one of the two surveys, or for some intermediate point, then the value of M obtained for that point should be used.

Step 2: calculation of proportions not orphaned for a hypothetical intersurvey cohort of respondents. The concept of a hypothetical cohort has already been discussed, and other uses of it appear in chapters II and III. The procedure followed in calculating the proportions not orphaned among a hypothetical intersurvey cohort of respondents depends upon the length of the interval between the surveys, which is denoted by T. The value of T should be a multiple of five, so that the survivors of a standard five-year age group at the earlier survey can be identified as belonging to a standard five-year age group at the second survey. If one denotes by $S(n, 1)$ the proportion of persons in the age group from n to $n+4$ whose mother was alive at the time of the first survey and by $S(n+T, 2)$ the equivalent proportion at the second survey, then $S(n+T, 2)$ is the proportion not orphaned at the second survey among the survivors of those whose proportion not orphaned at the first survey was $S(n, 1)$. Using this notation, and assuming that T is a multiple of five, the proportions not orphaned for a hypothetical intersurvey cohort, $S(n, s)$, are obtained as follows:

$$S(n,s) = S(n,2) \quad \text{for } n < T; \tag{B.14}$$

$$S(n,s) = S(n-T,s)\, S(n,2)/S(n-T,1) \quad \text{for } n \geq T. \tag{B.15}$$

TABLE 96. CALCULATION OF PROPORTIONS NOT ORPHANED FOR A HYPOTHETICAL INTERSURVEY COHORT, CONSTRUCTED EXAMPLE

Age group (1)	Age n (2)	Proportions not orphaned: First survey S(n, 1) (3)	Second survey S(n, 2) (4)	Intersurvey, S(n, s): Five-year interval (5)	10-year interval (6)
0-4	0	0.960	0.970	0.970[a]	0.970[a]
5-9	5	0.925	0.935	0.945	0.935[a]
10-14	10	0.881	0.895	0.914	0.904
15-19	15	0.790	0.805	0.835	0.814
20-24	20	0.692	0.720	0.761	0.739
25-29	25	0.574	0.605	0.666	0.623
30-34	30	0.447	0.474	0.550	0.506
35-39	35	0.355	0.387	0.476	0.420
40-44	40	0.223	0.274	0.367	0.310
45-49	45	0.109	0.159	0.262	0.188

[a] Proportions taken directly from second survey.

Step 3: calculation of survivorship probabilities. Once the proportions not orphaned for the hypothetical cohort have been calculated, survivorship probabilities are obtained from them and from the mean age at maternity, M, estimated in step 1 by using either the Brass or the regression method (see subsections B.2 (b) (ii) and B.2 (c) (ii)). The survivorship probabilities obtained from hypothetical-cohort data should reflect adult mortality levels during the intersurvey period, so there is no need in this case to estimate the reference period, $t(n)$, to which each estimate refers.

(iii) *A detailed example*

The only difference in the applications just described and the intersurvey method lies in the calculation of the proportions with surviving mother in a hypothetical cohort. Thus, a constructed example of the way in which to calculate these proportions (step 2) is given in table 96. Column (3) shows the proportions not orphaned at the first survey, classified by five-year age group; and column (4) shows the corresponding proportions at the second survey.

Column (5) shows the hypothetical-cohort proportions not orphaned for an intersurvey period of five years. To illustrate, the value for age group 15-19, 0.835, is obtained as follows (from equations (B.14) and (B.15)):

$$S(15, s) = 0.914(0.805/0.881) = 0.835.$$

It may be mentioned that this value may also be obtained by

$$S(15, s) = S(0, 2)S(5, 2)S(10, 2)S(15, 2)/$$

$$S(0, 1)S(5, 1)S(10, 1) =$$

$$(0.970)(0.935)(0.895)(0.805)/$$

$$(0.960)(0.925)(0.881) = 0.835.$$

Column (6) shows the hypothetical-cohort proportions not orphaned for an intersurvey period of 10 years. The value for age group 20-24, 0.739, is obtained as follows (from equations (B.14) and (B.15)):

$$S(20, s) = S(10, s)S(20, 2)/S(10, 1) =$$

$$(0.904)(0.720/0.881) = 0.739.$$

Again this value may be obtained by

$$S(20, s) = S(0, 2)S(10, 2)S(20, 2)/S(0, 1)S(10, 1)$$

$$= (0.970)(0.895)(0.720)/(0.960)(0.881) = 0.739.$$

Intersurvey adult survivorship probabilities, allowing for both mortality and fertility change (if M can be calculated from data at the beginning and at the end of the intersurvey period) can now be obtained by applying either the Brass or the regression method to the hypothetical-cohort proportions not orphaned (see subsections B.2 (b) (ii) and B.2 (c) (ii)).

3. *Estimation of adult survivorship based on proportions widowed*

(a) *Basis of method and its rationale*

The proportions of ever-married persons classified by age whose first spouse is still alive can be used to estimate adult survivorship probabilities in much the same way as the proportions not orphaned can be so used. In the case of widowhood, an additional possibility exists because the ever-married respondents can be classified by duration of marriage. In order to ensure that there shall be only one person at risk of dying per respondent and to minimize the problems arising because of remarriage, the data collected should refer only to the survival of the first spouse of each respondent. Hence, the measure of duration required is the time elapsed since the respondent's first union. Classification of the data by duration of first marriage has the methodological advantage of establishing directly the length of exposure to the risk of dying of the spouse; and it may have a very real practical advantage in some parts of the world, where duration of marriage appears to be more accurately reported than age. When data are classified by age, the length of exposure to the risk of dying has to be estimated from the current age of the respondent and a measure of the average age at marriage of all respondents.

The estimation of adult mortality based on information about widowhood status has several advantages over that based on the orphanhood status of respondents. Since only first marriages are being considered, there is in all cases only one respondent for each target person. Further, no type of adoption effect is likely to affect this type of data, so proportions not widowed for the shorter average exposure periods may produce acceptable survivorship estimates referring to more recent periods which are generally those of greater interest. Lastly, experience suggests that because the most reliable information about survival of first spouse is provided by women, these methods provide a fairly good means of estimating male adult mortality, the estimation of which from data on paternal orphanhood is the weakest both from a methodological point of view and for reasons related to data quality.

However, this estimation method shares several of the disadvantages associated with those based on orphanhood. Once more, the universe to which the estimated survival probabilities refer is not the entire population: in this case, they refer only to the ever-married portion of it. Yet, in countries where almost universal marriage is the rule, the biases that may be introduced by assuming that mortality risks among the never-married are similar to those estimated for the ever-married are likely to be small. A second disadvantage of this method is that it assumes that mortality and nuptiality have remained constant in the recent past and that the survival of the respondent is independent of that of his or her spouse, assumptions that are not likely to hold strictly in practice. In addition, a disadvantage specific to widowhood data classified by age is that the length of exposure to the risk of dying of a respondent's first spouse has to be estimated from the respondent's age and from a summary measure of age at first marriage, thus introducing yet another level of approximation. Lastly, in terms of data quality, it is likely that in cases where the respondent has remarried and shares a household with the new spouse, the interviewer may neglect to ask explicitly the question about survivorship of the first spouse.

There is little that the analyst can do to minimize the negative effects of some of these disadvantages on the final estimates of survivorship. With respect to data quality, it is obviously important to make sure that the interviewer understands the concepts being used and avoids mistakes such as that cited above. The assumption of constant mortality has been relaxed by the work of Brass and Bamgboye,[12] who propose a method to estimate the time reference of the survivorship probabilities derived from data on widowhood. Of course, the change of mortality assumed in deriving reference period estimates does not represent all possible patterns of change, but it is general enough to be adequate in most circumstances.

The assumption of constant nuptiality in the past can be relaxed if the mean ages of both respondents and their spouses at first marriage are estimated for each age or marriage-duration group of respondents. In such a case, the $SMAM_m$ and $SMAM_f$ values appearing in equations (B.17)-(B.26) should be replaced by age or duration-specific values (according to the respondents' age group being used). This approach is possible if reliable data on the retrospective marriage history of the population under study are available.

This introductory section may be concluded by pointing out that the widowhood methods presented in this chapter represent recent revisions of the procedures first proposed by Hill[13] and later revised by Hill and Trussell.[14]

(b) *Widowhood data classified by age*

(i) *Data required*

This method seeks to estimate male (female) probabilities of surviving from age 20 to age n from the following data:

(*a*) The observed singulate mean ages at marriage for men ($SMAM_m$) and for women ($SMAM_f$). For a description of the way in which to estimate these ages from the proportions single classified by age, see annex I. To calculate the proportions single in each age group, the basic data required are: the total male (female) population; and the male (female) population single, both classified by five-year age group;

(*b*) The proportion of ever-married women (men) in each five-year age group whose first husband (wife) was alive at the time of the interview. The proportion of respondents aged from n to $n+4$ with first spouse alive is denoted by $NW(n)$. Note that the set of proportions non-widowed, $NW(n)$, can be obtained by having as input any two of the following: (*a*) the number of respondents whose first spouse was alive at the time of the interview classified by five-year age group; (*b*) the number of respondents whose first spouse was dead classified by five-year age group; and (*c*) the total number of ever-married respondents who declared the survivorship status of their first spouse, also classified by five-year age group. Since category (*c*) is supposed to be the sum of the first two, it is important to make sure that it excludes all respondents who did not know or did not declare the survivorship status of their first spouse.

(ii) *Computational procedure*

The steps of the computational procedure are described below.

Step 1: calculation of proportions not widowed. The proportion of female (male) respondents not widowed in the age group from n to $n+4$, denoted by $NW(n)$, is equal to the ratio of female (male) respondents aged from n to $n+4$ whose first husband (wife) was alive at the time of the interview and the total number of ever-married female (male) respondents aged from n to $n+4$ who declared the survivorship status of their first husband (wife). Since the latter figure equals the sum of the female (male) respondents aged from n to $n+4$ with first husband (wife) alive and those of the same age group with first husband (wife) dead, knowledge of only these two categories of respondents is sufficient to calculate the desired proportions.

In order to estimate survivorship probabilities for males, the method requires that the proportions of females not widowed be known, while knowledge of the male proportions not widowed is necessary to estimate female survivorship probabilities.

Step 2: calculation of singulate mean age at marriage for both males and females. For a description of the procedure required to calculate the singulate mean age at marriage, $SMAM$, see annex I. Both values are necessary when estimating either male or female survivorship probabilities from widowhood data classified by age. Subindices f and m are used to distinguish the values referring to females from those referring to males.

Step 3: calculation of survivorship probabilities. The relationship between the variables calculated in the previous steps and certain probabilities of survivorship was established by using least-squares regression to fit the following equations:

$$l_m(n)/l_m(20) = a(n) + b(n)\, SMAM_f + c(n)\, SMAM_m + d(n)\, NW_f(n-5)$$

$$l_f(n)/l_f(20) = a(n) + b(n)\, SMAM_f + c(n)\, SMAM_m + d(n)\, NW_m(n) \qquad \text{(B.16)}$$

to data generated by using model mortality and nuptiality schedules (see chapter I). The estimated regression coefficients $a(n)$, $b(n)$, $c(n)$ and $d(n)$ are shown, for each value of n, in tables 97 and 98. Also shown in each

[12] W. Brass and E. A. Bamgboye, *op. cit.*

[13] K. Hill, "Estimating adult mortality levels from information on widowhood", *Population Studies*, vol. XXXI, No. 1 (March 1977), pp. 75-84.

[14] K. Hill and J. Trussell, *loc. cit.*

TABLE 97. COEFFICIENTS FOR ESTIMATION OF CONDITIONAL MALE SURVIVORSHIP PROBABILITIES FROM DATA ON THE WIDOWHOOD STATUS OF FEMALE RESPONDENTS

Age n (1)	Coefficients $a(n)$ (2)	$b(n)$ (3)	$c(n)$ (4)	$d(n)$ (5)
25.............	0.1082	−0.00209	0.00072	0.9136
30.............	−0.0284	−0.00465	0.00157	1.0822
35.............	−0.0159	−0.00638	0.00253	1.0831
40.............	0.0041	−0.00784	0.00395	1.0596
45.............	0.0152	−0.00953	0.00611	1.0324
50.............	0.0087	−0.01189	0.00925	1.0144
55.............	−0.0169	−0.01515	0.01353	1.0111
60.............	−0.0590	−0.01940	0.01880	1.0291

Estimation equation:

$$l_m(n)/l_m(20)=a(n)+b(n)SMAM_f+c(n)SMAM_m+d(n)NW_f(n-5)$$

TABLE 98. COEFFICIENTS FOR ESTIMATION OF CONDITIONAL FEMALE SURVIVORSHIP PROBABILITIES FROM DATA ON THE WIDOWHOOD STATUS OF MALE RESPONDENTS

Age n (1)	Coefficients $a(n)$ (2)	$b(n)$ (3)	$c(n)$ (4)	$d(n)$ (5)
25.............	−0.0208	0.00052	−0.00137	1.0451
30.............	−0.2135	0.00104	−0.00329	1.2791
35.............	−0.1896	0.00162	−0.00492	1.2884
40.............	−0.1290	0.00236	−0.00624	1.2483
45.............	−0.0713	0.00340	−0.00742	1.2005
50.............	−0.0327	0.00502	−0.00860	1.1590
55.............	−0.0139	0.00749	−0.01019	1.1297

Estimation equation:

$$l_f(n)/l_f(20)=a(n)+b(n)SMAM_f+c(n)SMAM_m+d(n)NW_m(n)$$

table is the estimation equation to be used in each case. Note that according to table 97 male survivorship probabilities are estimated by using as input the proportions of non-widowed females, while according to table 98 female survivorship probabilities are estimated from the observed proportions of non-widowed males.

Step 4: calculation of number of years before the survey to which survivorship estimates refer. In cases where mortality has been changing regularly (that is, when the change can be assumed to be linear on the logit scale) during the 15 or 20 years preceding the survey, estimates of the time, denoted by $t(n)$, to which each of the survivorship probabilities obtained in the previous step refers can be calculated by using the following equations:

$$u_m(n)=0.3333\ \ln NW_f(n-5)+ Z(SMAM_m+n-2.5-SMAM_f) +0.0037(27.0-SMAM_m) \quad (B.17)$$

$$t_m(n)=(n-2.5-SMAM_f)(1.0-u_m(n))/2.0 \quad (B.18)$$

or

$$u_f(n)=0.3333\ \ln NW_m(n)+ Z(SMAM_f+n+2.5-SMAM_m) +0.0037(27.0-SMAM_f) \quad (B.19)$$

$$t_f(n)=(n+2.5-SMAM_m)(1.0-u_f(n))/2.0 \quad (B.20)$$

Equations (B.17) and (B.18) are to be used when the estimated survivorship probabilities refer to males, while equations (B.19) and (B.20) are to be used when they refer to females. Note that the form of these sets of two equations is essentially the same, with the subindices indicating the sex category reversed. In both cases (males and females), the quantity $n+2.5-SMAM$ is used as an indicator of the mean duration of first marriage of respondents aged from n to $n+4$, and the values of the standard function $Z(x)$ are obtained by interpolating linearly between those listed in table 88. As the detailed example illustrates, the use of these equations is simple; and the timing estimates they yield, though not exact, are adequate indicators of the reference periods to which survivorship probabilities apply, if the change in mortality has been fairly steady and smooth.

(iii) *A detailed example*

Considered here is the case of ever-married women who were questioned about the survival status of their first husband during the National Demographic Survey of Bolivia, carried out between 15 June and 31 October 1975.[15] Data gathered by this survey have already been used in illustrating the application of the estimation method based on the orphanhood status of respondents.

The steps of the computational procedure are given below.

Step 1: calculation of proportions not widowed. Table 99 shows the raw data gathered by the survey and the pro-

[15] K. Hill, H. Behm and A. Soliz, *op. cit.*

TABLE 99. EVER-MARRIED FEMALE POPULATION AND NUMBER OF WOMEN WHOSE FIRST HUSBAND WAS DEAD AT TIME OF INTERVIEW, BY AGE GROUP, BOLIVIA, 1975

Age group (1)	*Ever-married female population* (2)	*Women whose first spouse was dead* (3)	*Proportion not widowed (female respondents)* (4)
20-24	1 187	24	0.9798
25-29	1 515	41	0.9729
30-34	1 276	62	0.9514
35-39	1 494	124	0.9170
40-44	1 115	141	0.8735
45-49	1 202	217	0.8195
50-54	774	228	0.7054
55-59	612	213	0.6520

portions of ever-married women whose husbands were still alive at the time of the interview. $NW_f(n)$. In computing these proportions, the denominator used is the number of ever-married women rather than all women and there were no cases of non-response. The proportions $NW_f(n)$ shown in column (4) are obtained by dividing the number of women with first husband dead (appearing in column (3) of table 99) by the number of ever-married women reporting first husband's survivorship status (listed in column (2)) and subtracting the result from 1.0. Thus, $NW_f(25)$ is calculated as

$$NW_f(25) = 1.0-(41/1{,}515) = 1.0-0.0271 = 0.9729.$$

Step 2: calculation of singulate mean age at marriage for both males and females. For a detailed explanation of the way in which to calculate the necessary *SMAM* values, see annex I. In the case of Bolivia in 1975, these values are: $SMAM_m = 25.3$ years; and $SMAM_f = 23.2$ years.

Step 3: calculation of survivorship probabilities for males. Using the coefficients shown in table 97 and applying the version of equation (B.16) appearing in this table with $SMAM_f = 23.2$ years, $SMAM_m = 25.3$ years, and the observed proportions not widowed, $NW_f(n)$, the survivorship probabilities listed in column (6) of table 100 are obtained. As an example, $l_m(50)/l_m(20)$ is calculated below:

$$l_m(50)/l_m(20) = 0.0087 - 0.01189(23.2) + 0.00925\,(25.3)$$
$$+1.0144\,(0.8195)$$
$$= 0.798.$$

Also shown in table 100 (column (7)) are the mortality levels to which each estimated survivorship probability corresponds in the Coale-Demeny West family of model life tables. These levels are obtained by interpolating linearly between the values listed in table 226 (see annex VII). See step 3 of subsection B.2 (b) (iii) for a detailed example of the interpolation procedure used.

Step 4: calculation of number of years before the survey to which the male survivorship probabilities refer. Since male survivorship is being estimated, equations (B.17) and (B.18) are used to calculate this reference period, denoted by $t(n)$. Table 101 shows the necessary input

TABLE 100. ESTIMATION OF MALE SURVIVORSHIP PROBABILITIES FROM INFORMATION ON SURVIVAL OF FIRST HUSBAND, BOLIVIA, 1975

Age group (1)	*Age n* (2)	*Intermediate value* $a(n)+b(n)(23.2)+c(n)(25.3)$ (3)	*Coefficient* $d(n)$ (4)	*Proportion not widowed* $NW_f(n-5)$ (5)	*Adult male survivorship probability* $l_m(n)/l_m(20)$ (6)	*West mortality level* (7)
20-24	25	0.0779	0.9136	0.9798	0.973	14.3
25-29	30	−0.0966	1.0822	0.9729	0.956	16.3
30-34	35	−0.0999	1.0831	0.9514	0.931	16.6
35-39	40	−0.0779	1.0596	0.9170	0.894	15.7
40-44	45	−0.0513	1.0324	0.8735	0.850	15.4
45-49	50	−0.0331	1.0144	0.8195	0.798	15.3
50-54	55	−0.0261	1.0111	0.7054	0.687	13.3
55-59	60	−0.0334	1.0291	0.6520	0.638	14.7

TABLE 101. ESTIMATION OF TIME REFERENCE PERIODS FOR MALE SURVIVORSHIP PROBABILITIES DERIVED FROM INFORMATION ON SURVIVAL OF FIRST HUSBAND, BOLIVIA, 1975

Age n (1)	*Proportion not widowed* $NW_f(n-5)$ (2)	*Length of exposure indicator* $x_m(n)$ (3)	*Standard function* $Z_m(x)$ (4)	*Correction function* $u_m(n)$ (5)	*Reference period*[a] $t_m(n)$ (6)	*Reference date* (7)	*West mortality level* (8)
30.............	0.9729	29.6	0.090	0.0871	2.0	1973.6	16.3
35.............	0.9514	34.6	0.091	0.0807	4.3	1971.3	16.6
40.............	0.9170	39.6	0.102	0.0794	6.6	1969.0	15.7
45.............	0.8735	44.6	0.135	0.0962	8.7	1966.9	15.4
50.............	0.8195	49.6	0.189	0.1289	10.6	1965.0	15.3
55.............	0.7054	54.6	0.253	0.1430	12.6	1963.0	13.3
60.............	0.6520	59.6	0.331	0.1947	13.8	1961.8	14.7

[a] Number of years prior to the survey to which survivorship estimates refer.

information and some of the intermediate results. The observed proportions of females who were not widowed, $NW_f(n-5)$, are listed in column (2); and the values of $(SMAM_m + n - 2.5 - SMAM_f)$ for each n are denoted by $x_m(n)$ and are listed in column (3). The function Z is calculated for each of these $x_m(n)$ values by interpolating in table 88. Note that the data for the first value of n, 25, have been excluded from table 101 because the tabulated values of Z do not cover the value of $x(25) = 25.6$; and although extrapolation is possible, it leads to an estimate of $t(25)$ that is negative, a clearly unacceptable outcome. However, this result indicates that in a population where the female singulate mean age at marriage is 23 and that of males is 25, an estimate of the male probability of surviving from age 20 to age 25 derived from reports of ever-married females aged 20-24 is likely to be fairly poor, since a sizeable proportion of the women in this age group are not yet married and the mean exposure to the risk of dying of their husbands is relatively short. Such an indication is corroborated, in this case, by the fact that the mortality level associated with $l_m(25)/l_m(20)$ is quite clearly out of line with the subsequent estimates (see table 100).

Returning to the calculation of $Z(x)$, the procedure followed in the case of $n = 45$ is illustrated. First:

$$x_m(45) = 25.3 + 45.0 - 2.5 - 23.2 = 44.6$$

then

$$Z_m(44.6) = 0.4(0.130) + 0.6(0.139) = 0.135.$$

Therefore, using equation (B.17),

$$\begin{aligned} u_m(45) &= 0.3333 \ln NW_f(40) + Z(44.6) + 0.0037(1.7) \\ &= 0.3333 \ln(0.8735) + 0.135 + 0.0063 \\ &= 0.0962; \end{aligned}$$

and according to equation (B.18),

$$\begin{aligned} t_m(45) &= (45.0 - 2.5 - 23.2)(1.0 - 0.0962)/2.0 \\ &= (9.65)(0.9038) = 8.7. \end{aligned}$$

That is, the estimate of $l_m(45)/l_m(20)$, which corresponds to a West mortality level of 15.4, refers approximately to 8.7 years before the survey; and since the latter has as reference date 1975.6 (see step 4 of subsection B.2 (b) (iii), the reference date for $l_m(45)/l_m(20)$ is the end of 1966, as shown in column (7) of table 101.

The mortality levels associated with the survivorship probabilities obtained in the previous step are listed in column (8) of table 101 to allow a quick assessment of the results obtained. It is worth taking note that, disregarding the last estimate ($l_m(60)/l_m(20)$), the adult mortality trend followed by the other estimates seems rapid though not impossible, implying a gain of some three mortality levels (or approximately 7.5 years in expectation of life) during 10 years or so. If the estimate associated with $l_m(55)/l_m(20)$, referring to approximately 1963, is also disregarded, the improvement in adult mortality is more modest (about one level) and perhaps somewhat more plausible. Unfortunately, the mortality levels that refer to periods comparable to those already estimated for Bolivia from maternal orphanhood data (see tables 92 and 95) do not quite match the latter; and although they refer to different sexes (the orphanhood estimates refer to female mortality, while those derived here correspond to males), the lack of consistency observed suggests that at least one of these sets of estimates may be seriously deficient. Although at this stage it seems more likely, given the trend they imply, that the estimates derived from orphanhood information are the deficient set, further evidence is required to make a definite decision.

(c) *Widowhood data classified by duration of first marriage*

(i) *Data required*

Male (or female) probabilities of surviving from age 20 to age n can also be estimated from data on survival of first spouse tabulated by duration of marriage (measured as the time elapsed since first union). The specific data required for the application of this variant of the method are listed below:

(*a*) The observed singulate mean age at marriage, *SMAM*, for males (females). This age is estimated from the proportion of single males (females) in each five-year age group. For a detailed description of the procedure used in estimating the singulate mean age at marriage, see annex I. Observe that when widowhood data are classified by duration of first marriage, only one value of *SMAM* is needed in each case: if male mortality is being estimated from data from female respondents, only the value of *SMAM* for males is required; and vice versa;

(*b*) The proportion of ever-married women (men) whose first husbands (wives) were alive at the time of the interview, classified by five-year duration-of-marriage group. These proportions are again denoted by $NW(k)$, where k now represents the lower limit of each duration group, that is, $NW(k)$ is the proportion not widowed among respondents first married from k to $k + 4$ years before the survey. As in the case of data classified by age, the proportions not widowed can be calculated from any two of the following: (*a*) the number of respondents whose first spouse was alive at the time of the interview classified by five-year duration group; (*b*) the number of respondents whose first spouse was dead at the time of the interview classified by five-year duration group; (*c*) the total number of ever-married respondents who declared the survivorship status of their first spouse, classified by five-year duration group. Since category (*c*) is supposed to be the sum of the first two, it is important that it exclude all respondents who did not know or did not declare the survivorship status of their first spouse.

(ii) *Computational procedure*

The steps of the computational procedure are described below.

Step 1: calculation of proportions not widowed among *female (male) respondents.* The proportion of female (male) respondents not widowed in the duration group from k to $k + 4$, denoted by $NW(k)$, is equal to the ratio of the number of female (male) respondents first married from k to $k + 4$ years earlier whose first husband (wife) was alive at the time of the interview divided by the total number of ever-married female (male) respondents in the same duration group who declared the survivorship status of their first husband (wife).

Note that male survivorship probabilities are estimated from the proportions of non-widowed females, whereas female survivorship probabilities are estimated from male proportions not widowed.

Step 2: calculation of singulate mean age at marriage for males (females). The necessary value of *SMAM* is calculated according to the procedure described in annex I. Note that the value of *SMAM* required is that corresponding to the sex category for which survivorship probabilities are being estimated.

Step 3: calculation of survivorship probabilities for males (females). When male mortality is being estimated, the probability of survival from age 20 is related to the singulate mean age at marriage for males and the proportion of women in a given duration-of-marriage group with a surviving first husband. The following equation is used:

$$l_m(n)/l_m(20) = a(n) + b(n)\,SMAM_m + c(n)\,NW_f(n-25) \quad \text{(B.21)}$$

where $a(n)$, $b(n)$ and $c(n)$ are the coefficients shown in table 102; and $NW_f(n-25)$ is the proportion of women in the duration group from $n-25$ to $n-21$ having a surviving first husband. As in the case of the method based on data classified by age, the coefficients of equation (B.21) were estimated by using least-squares regression to fit this equation to data generated from model mortality and nuptiality schedules (see chapter I).

An equivalent relation is used to estimate female survival probabilities, namely,

$$l_f(n)/l_f(20) = a(n) + b(n)\,SMAM_f + c(n)\,NW_m(n-25) \quad \text{(B.22)}$$

TABLE 102. COEFFICIENTS FOR ESTIMATION OF CONDITIONAL MALE SURVIVORSHIP PROBABILITIES FROM THE WIDOWHOOD STATUS OF FEMALE RESPONDENTS, CLASSIFIED BY DURATION OF MARRIAGE

Age n (1)	Duration group (2)	Coefficients $a(n)$ (3)	Coefficients $b(n)$ (4)	Coefficients $c(n)$ (5)
25.............	0-4	−1.0084	0.00039	1.9989
30.............	5-9	−0.3214	0.00098	1.2976
35.............	10-14	−0.1990	0.00202	1.1503
40.............	15-19	−0.1695	0.00353	1.0849
45.............	20-24	−0.1798	0.00557	1.0477
50.............	25-29	−0.2187	0.00814	1.0278

Estimation equation:
$l_m(n)/l_m(20) = a(n) + b(n)SMAM_m + c(n)NW_f(n-25)$

where the male proportion not widowed and the female *SMAM* replace the female proportion not widowed and the male *SMAM* of equation (B.21). Note, however, that the estimated regression coefficients to be used also change; those listed in table 102 are to be employed in estimating male survivorship, while those given in table 103 should be employed in estimating the survivorship probabilities for females.

TABLE 103. COEFFICIENTS FOR ESTIMATION OF CONDITIONAL FEMALE SURVIVORSHIP PROBABILITIES FROM THE WIDOWHOOD STATUS OF MALE RESPONDENTS, CLASSIFIED BY DURATION OF MARRIAGE

Age n (1)	Duration group (2)	Coefficients $a(n)$ (3)	Coefficients $b(n)$ (4)	Coefficients $c(n)$ (5)
25.............	0-4	−1.2183	0.00141	2.1900
30.............	5-9	−0.3944	0.00147	1.3642
35.............	10-14	−0.2443	0.00184	1.2061
40.............	15-19	−0.2060	0.00279	1.1480
45.............	20-24	−0.2073	0.00428	1.1188
50.............	25-29	−0.2349	0.00639	1.1025

Estimation equation:
$l_f(n)/l_f(20) = a(n) + b(n)\,SMAM_f + c(n)\,NW_m(n-25)$

Step 4: calculation of number of years before the survey to which male survivorship probabilities refer. In cases where mortality has been changing regularly during the 15 or 20 years preceding the survey (that is, when the change in mortality has been roughly linear on the logit scale), estimates of the time to which each of the survivorship probabilities obtained in the previous step refers can be calculated using the following equations:

$$u_m(n) = 0.3333 \ln NW_f(n-25) + Z(n-22.5+SMAM_m) + 0.0037(27-SMAM_m) \quad \text{(B.23)}$$

$$t_m(n) = (n-22.5)(1.0-u_m(n))/2.0 \quad \text{(B.24)}$$

or

$$u_f(n) = 0.3333 \ln NW_m(n-25) + Z(n-22.5+SMAM_f) + 0.0037(27-SMAM_f) \quad \text{(B.25)}$$

$$t_f(n) = (n-22.5)(1.0-u_f(n))/2.0. \quad \text{(B.26)}$$

Equations (B.23) and (B.24) are used when the estimated survivorship probabilities refer to males, while equations (B.25) and (B.26) are used when they refer to females. Note that the form of these sets of equations is essentially the same, with the subindices indicating sex category reversed. In both cases (males and females), the quantity $n-22.5$ is the mid-point of the duration group to which the respondents belong, and the values of the function $Z(x)$ are obtained by interpolating linearly between those listed in table 88.

(iii) *A detailed example*

The use of data on the survivorship of first spouse classified by duration of marriage to estimate adult survivorship probabilities is illustrated by using data gathered by the National Demographic Survey carried out in Panama between August and October 1976. Table 104 shows ever-married males classified by time since first marriage and survival of first spouse. The survivorship probabilities to be estimated refer to females. Note that in table 104 the number of men who said they had been married, but who did not know the duration of their marriage, constituted a sizeable proportion of the total (slightly over 10 per cent). This level of non-response suggests that the data may not be reliable: in a country where some 10 per cent of the married male population does not declare or does not know the duration of their marriage, it is unlikely both that duration will be correctly reported by the rest and that those of unknown duration have the same characteristics as those who declared a duration. One possible treatment for the cases of non-response is to divide them among the different durations according to the proportions implied by the known cases. This procedure would be based on the assumption that, for a given survival of first spouse (dead or alive), all persons are equally likely to fail to state the duration of their union. However, it seems reasonable to suppose that people belonging to unions that have lasted longer are more likely to have forgotten the date when the union began, so a more complicated redistribution procedure should probably be used. Yet, such a procedure would require that an assumption be made about how the probability of not stating a date of first union changes according to the time elapsed since the union began. Because no information is available on this matter, the likelihood of introducing substantial biases in the final results by making incorrect assumptions is high. In view of this possibility, it seems safer to ignore completely the cases of unknown duration when carrying out this analysis, while bearing their existence in mind at the point of interpreting the final results.

The computational procedure for this example is given below.

Step 1: calculation of proportions not widowed among male respondents. Table 104 shows all the data categories that can be derived from a simple question on the survivorship status of the first wife of each ever-married male respondent. For some duration groups, the number of respondents who did not declare the survivorship status of first wife constitutes a sizeable proportion of those who declared that their first wives were dead. Again, this characteristic of the data renders their quality suspect, since if one were to assume that all cases of non-response were, in fact, cases of dead first wives, the survivorship estimates obtained would be substantially different, especially at lower marriage durations. Strictly speaking, however, there is no basis for making such an assumption; and in the rest of this analysis, the respondents who did not declare the survivorship status of their first wife are ignored. Therefore, to calculate the proportion of respondents not widowed, $NW_m(k)$ in duration group 10-14, for example, the number with first wife alive is divided by the sum of those with first wife alive and those with first wife dead, as shown below:

$$NW_m(10) = 1{,}096/(1{,}096+23) = 0.9794.$$

Note that $NW_m(10)$ can also be obtained by dividing the number with first wife alive by the difference between all possible respondents and those whose wives' survival status is not known. Thus,

$$NW_m(10) = 1{,}096/(1{,}127-8) = 0.9794.$$

The full set of $NW_m(k)$ values is shown in column (7) of table 104.

Step 2: calculation of singulate mean age at marriage for females. For a detailed description of the procedure to be used in calculating the values of *SMAM* for females, see annex I. In this case, $SMAM_f$ was found to equal 22.01 years.

Step 3: calculation of survivorship probabilities for females. Equation (B.22) is used to calculate the female probabilities of surviving from age 20 to age n. These probabilities are calculated by using as input the proportions not widowed among ever-married respondents, the female singulate mean age at marriage, and the coefficients listed in table 103. Table 105 shows the details of the calculations. Note that the final estimates of survivorship probabilities are not, in this case, very different from the original proportions of respondents with a surviving first wife. The West mortality level associated with each survivorship probability has been estimated by interpolating linearly between the values shown in table 222 in annex VII (see step 3 of subsection

TABLE 104. DATA ON SURVIVORSHIP STATUS OF FIRST WIFE, MALE RESPONDENTS, PANAMA, 1976

Duration group (1)	Index k (2)	Number of male respondents: With first wife alive (3)	With first wife dead (4)	Status of first wife not declared (5)	Total (6)	Proportion not widowed $NW_m(k)$ (7)
0-4	0	1 342	4	2	1 348	0.9970
5-9	5	1 419	15	4	1 438	0.9895
10-14	10	1 096	23	8	1 127	0.9794
15-19	15	960	34	7	1 001	0.9658
20-24	20	808	49	6	863	0.9428
25+	-	2 070	526	50	2 646	-
Unknown		594	169	212	975	-

TABLE 105. ESTIMATION OF ADULT FEMALE SURVIVORSHIP PROBABILITIES FROM MALE DATA ON SURVIVAL OF FIRST SPOUSE, BY DURATION OF MARRIAGE, PANAMA, 1976

Duration group (1)	*Age* n (2)	*Proportion not widowed (male respondents)* (3)	*Estimation equation* $a(n) + b(n)\,SMAM_f + c(n)NW_m(n-25)$ (4)	*Adult female survivorship probability* $l_f(n)/l_f(20)$ (5)	*West mortality level* (6)
0-4..........	25	0.9970	−1.2183 + 0.00141(22.01) + 2.1900(0.9970)	0.9962	22.2
5-9..........	30	0.9895	−0.3944 + 0.00147(22.01) + 1.3642(0.9895)	0.9878	21.3
10-14........	35	0.9794	−0.2443 + 0.00184(22.01) + 1.2061(0.9794)	0.9775	21.0
15-19........	40	0.9658	−0.2060 + 0.00279(22.01) + 1.1480(0.9658)	0.9641	20.8
20-24........	45	0.9428	−0.2073 + 0.00428(22.01) + 1.1188(0.9428)	0.9417	20.4

B.2 (b) (iii) for a detailed example of the procedure for calculating them). These levels imply, in general, that mortality among females in Panama was very low during the early 1970s.

Step 4: calculation of number of years before the survey to which the male survivorship probabilities refer. The West mortality levels shown in column (6) of table 105 suggest that mortality has not remained constant in Panama, since the reports of respondents who have been married for a longer period of time are associated with lower levels (that is, higher mortality) than are those associated with the reports of respondents married for a shorter and more recent period. It is important, therefore, to obtain some indication about the time periods, denoted by $t(n)$, to which the estimated survivorship probabilities refer. Equations (B.25) and (B.26) are therefore used to estimate $t_f(n)$. Table 106 shows some of the intermediate values required for their calculation and the final $t_f(n)$ estimates. The values of $Z_f(x)$ are obtained by interpolating linearly between the values listed in table 88, and $x_f(n)$ is used to denote the quantity $n-22.5+SMAM_f$. Since the survey took place between August and October of 1976, the mid-point of this period, corresponding in decimal form to 1976.7, is used as its reference date (see step 4 of subsection B.2 (b) (iii) for an example of how to calculate the decimal equivalent of this mid-point). Hence, by subtracting the estimated $t_f(n)$ values from 1976.7, the date to which each survivorship probability refers can be obtained. These reference dates are shown in column (7) of table 106; and to facilitate comparison, the West mortality levels obtained in the previous step are listed in column (8) of the same table. Without any other evidence, the trend of the dated survivorship estimates implying an improvement in adult female mortality of about a quarter of a level per annum seems plausible, although the estimated levels are relatively high. Because of the deficiencies noted earlier in this data set, the possibility that the reports on widowhood status of male respondents may understate true widowhood levels must be explored further before the estimates shown in table 105 can be fully accepted.

(d) *Use of widowhood data from two surveys*

Mortality estimates from widowhood share with those from orphanhood the problem of referring to periods located a substantial length of time before the survey, and the time reference of the estimates can only be identified when mortality has been changing regularly. A method for obtaining estimates or mortality that refer to a well-defined period of time by using orphanhood data from two surveys has been suggested earlier. Strictly speaking, a parallel approach cannot be used with widowhood data classified by age of respondent because age groups do not define marriage cohorts; and the change in proportions not widowed from one age group to the next is generally deflated by the influx of newly married respondents whose exposure to the risk of dying while married is below the average of the group. However, the same phenomena affect the proportions not widowed by age group at each survey; thus, as long as age patterns of marriage remain more or less constant, the proportions not widowed for a hypothetical intersurvey cohort will be representative of the intersurvey mortality experience. These proportions can be calculated following the method described in the case of

TABLE 106. ESTIMATION OF TIME REFERENCE PERIODS FOR FEMALE SURVIVORSHIP PROBABILITIES DERIVED FROM MALE WIDOWHOOD DATA, PANAMA, 1976

Age n (1)	*Proportion not widowed* $NW_m(n-25)$ (2)	*Length of exposure indicator* $x_f(n)$ (3)	*Standard function* $Z_f(n)$ (4)	*Correction function* $u_f(n)$ (5)	*Reference period*[a] $t_f(n)$ (6)	*Reference date* (7)	*West mortality level* (8)
25.............	0.9970	24.5	0.090	0.1075	1.1	1975.6	22.2
30.............	0.9895	29.5	0.090	0.1049	3.4	1973.3	21.3
35.............	0.9794	34.5	0.091	0.1025	5.6	1971.1	21.0
40.............	0.9658	39.5	0.102	0.1089	7.8	1968.9	20.8
45.............	0.9428	44.5	0.135	0.1338	9.7	1967.0	20.4

[a] Number of years prior to the survey to which survivorship estimates refer.

orphanhood data (see subsection B.2 (d)) and can then be analysed by using the method described in subsection B.3 (b), with average male and female singulate mean ages at marriage during the intersurvey period as additional inputs (these average ages can be calculated as the mean of those corresponding to the beginning and end of the intersurvey period).

On the other hand, when widowhood data are classified by time elapsed since first marriage, five-year duration groups do represent marriage cohorts; and proportions not widowed for a hypothetical marriage cohort representing intersurvey experience may be calculated from two sets of observed proportions not widowed classified by duration and obtained from surveys or censuses five or 10 years apart. The calculation of the proportions not widowed representing the experience of a hypothetical intersurvey cohort is carried out exactly as described in step 2 of subsection B.2 (d) (ii) for the case of proportions not orphaned, with duration groups substituted throughout for age groups. Because the complete computational procedure to be followed in this case is very similar to that followed in the case of data on orphanhood and because no data sets on widowhood by duration from two surveys are as yet available, a detailed description of the application of this method is omitted.

C. Estimation of survivorship to adulthood from birth

1. *General characteristics of methods*

In this section, an extension of the conditional methods discussed in section B is presented. The methods that are described allow the estimation of probabilities of survival from birth, that is, of probabilities that are no longer conditional. These probabilities are estimated by means of equations that include $l(2)$, the probability of surviving from birth to exact age 2, as an independent variable, to take account of mortality in childhood. In practice, the value of $l(2)$ used is almost invariably obtained by applying the child mortality estimation techniques described in chapter III.

Since the methods to be presented here are extensions of the conditional methods of adult survivorship estimation described above, they are based on very similar assumptions. In fact, all the comments made in section B about the validity of the estimates of conditional survivorship probabilities apply also to the validity of estimates of direct probabilities; and because the calculation of the latter values demands extra information, for example, $l(2)$, certain other assumptions are necessary.

The methods presented here are based on equations fitted by least-squares regression to simulated data, so the main assumption made is that the models used in simulating data represent reality adequately. An additional assumption necessary in this case is that the relationship between adult and child mortality embodied in the model life tables used during simulation cover the range of actual experience. Therefore, estimates derived by these methods are likely to be unreliable whenever the experience of the population studied falls outside the range covered by the models used. The estimation of adult survivorship from birth is particularly sensitive to the relationship between child and adult mortality, and to the pattern of the mortality schedule between ages 5 and 25. This sensitivity can be reduced by including in the estimation equation an independent variable allowing for known variations in mortality between ages 2 and 20 or 25. The model cases to which the estimation equations were fitted were generated by using mortality schedules based on the logit system, using as standards the four life tables for females at level 16 of the Coale-Demeny models. Therefore, the probability of surviving from age 2 to age 20 (or 25 in the case of orphanhood) in the appropriate standard life table is included as an independent variable in the estimation equation in order to allow for the age pattern of mortality between childhood and early adulthood. It remains true, however, that estimates of survivorship from birth based on orphanhood or widowhood data from younger respondents are overwhelmingly determined by the estimation of $l(2)$, while the proportions not orphaned or not widowed have a relatively low predictive value,[16] a fact that may affect the consistency of the estimates obtained from data corresponding to younger respondents.

It has been stressed earlier in this chapter that orphanhood and widowhood data provide estimates of mortality referring to points in the past and that if the same type of data is available from two surveys five or 10 years apart, the experience of a hypothetical intersurvey cohort can be constructed to obtain estimates of mortality referring exactly to the intersurvey period. The methods of analysis outlined in the next sections can also be applied to the constructed proportions not orphaned or not widowed of a hypothetical intersurvey cohort, using as input either an estimate of $l(2)$ obtained also from the constructed experience of a hypothetical cohort and thus referring to the same period (see chapter III, section D); or, failing that, an estimate of $l(2)$ obtained from women aged 20-24 at the second survey and thus referring more or less to the mid-point of the intersurvey period. Once the proportions not orphaned or not widowed for the hypothetical intersurvey cohort have been obtained, the analysis follows exactly the procedures described below in subsections C.2 (c), C.3 (b) (ii) and C.3 (c) (ii), but the mortality estimates obtained have a well-defined reference period (the intersurvey period), so that estimates of $t(n)$ are not required.

2. *Estimation of female survivorship from birth to adult ages on the basis of proportions with surviving mother*

(a) *Basis of method and its rationale*

Regression techniques were used to relate the proportions of respondents whose mothers were still alive at the time of the interview to the survivorship probabilities experienced by these women. It was found that probabilities of survivorship from birth, $l(n)$, could be

[16] K. Hill and J. Trussell, *loc. cit.*

estimated with sufficient accuracy if the probability of surviving from birth to age 2 for females—$l_f(2)$—were taken into account among the independent variables determining the desired $l(n)$ values and if an indicator of the relationship between adult and child mortality, denoted by RS and equal to the ratio of $l(25)$ to $l(2)$ in the standard that best represents the experience of the population in question, were also included in the fitted equation. As in the case of the conditional regression method based on information about maternal orphanhood (see subsection B.2 (c)), the other independent variables used are M, the mean age of mothers at the birth of their children, and $S(n)$, the proportion of respondents in the age group from n to $n+4$ whose mother is still alive. The form of the fitted equation is

$$l_f(25+n)=a(n)+b(n)M+c(n)\,l_f(2)S(n-5)+d(n)RS \qquad \text{(C.1)}$$

where $a(n)$, $b(n)$, $c(n)$ and $d(n)$ are coefficients whose values for each n are listed in table 107.

These coefficients were obtained by using least-squares regression to fit equation (C.1) to data simulated on the basis of selected fertility and mortality schedules. The fertility schedules used were derived from the Coale-Trussell models (see chapter I, subsection E.1) and the mortality schedules were obtained by using the logit system, using as standards the level 16 female life tables from each regional family of the Coale-Demeny models (see chapter I, subsections B.2 and B.4).

It is worth pointing out that this method allows only the estimation of female adult mortality, since the coefficients shown in table 107 were derived exclusively from simulations referring to females. Furthermore, these simulations do not take into account any trends in mortality; that is, the same life table was used in each simulated case to generate $l_f(2)$ and $l_f(25+n)$ for n ranging from 20 to 50. Therefore, use of the coefficients listed in table 107 implies the tacit assumption of an unchanging mortality level for a period of at least 40 years. Since, in practice, this assumption is very likely to be violated, one cannot interpret the estimates obtained by applying this method as being exact period measures of mortality, especially because the use of $l_f(2)$ as an independent variable introduces yet another timing problem. In fact, probably the most satisfactory way of using this method is by calculating first the time period to which the estimates of survivorship would refer, were they determined mainly by the proportions with surviving mother (as in the conditional method) and had mortality followed a regular pattern of change (linear in the logit scale), and then using as input for equation (C.1) child mortality estimates referring to corresponding periods in order to obtain dated probabilities of surviving from birth to adult ages. In practice, however, it will seldom be possible to obtain child mortality estimates for the exact dates to which the conditional survivorship probabilities refer, and period averages will have to be used instead. In such cases, the user must bear in mind that the survivorship estimates obtained from equation (C.1) reflect a mixture of mortality levels with somewhat different reference dates.

(b) *Data required*

The following data are required for this method:

(*a*) The proportion of respondents with a surviving mother in each five-year age group from n to $n+4$, denoted by $S(n)$. See subsection B.2 (b) (i) for some comments on the calculation of these proportions;

(*b*) The number of births in a given year, classified by five-year age group of mother. This information is used to estimate M, the mean age of mothers of a particular group of births at the time of such births;

(*c*) An estimate or estimates of the probability of surviving from birth to exact age 2 for females, denoted by $l_f(2)$. Such estimates are usually obtained from information on the number of children ever born and surviving classified by age of mother (see chapter III).

(c) *Computational procedure*

The computational procedure includes the steps described below.

Step 1: calculation of mean age at maternity. See step 1 in subsection B.2 (b) (ii).

Step 2: calculation of reference periods of the conditional survivorship probabilities estimated from information on

TABLE 107. COEFFICIENTS FOR ESTIMATION OF FEMALE SURVIVORSHIP PROBABILITIES FROM BIRTH ON THE BASIS OF PROPORTIONS OF RESPONDENTS WITH MOTHER ALIVE

Age n (1)	Coefficients $a(n)$ (2)	$b(n)$ (3)	$c(n)$ (4)	$d(n)$ (5)
20	−1.2982	0.0033	1.2275	1.0422
25	−1.2508	0.0051	1.1934	0.9821
30	−1.2385	0.0077	1.1623	0.9334
35	−1.2669	0.0115	1.1423	0.8885
40	−1.3217	0.0166	1.1432	0.8206
45	−1.3541	0.0225	1.1678	0.6889
50	−1.2655	0.0274	1.1932	0.4565

Estimation equation:
$l_f(25+n)=a(n)+b(n)M+c(n)\,l_f(2)\,S(n-5)+d(n)RS$

maternal orphanhood. The procedure described in step 3 in subsection B.2 (c) (ii) should be followed.

Step 3: estimation of probability of surviving from birth to age 2 for females. Reference should be made to the methods described in chapter III. Ideally, estimates of the probability of surviving to age 2, denoted by $l_f(2)$, should be obtained for each of the reference periods estimated in step 2. Only estimates of $l(2)$ for females are needed.

Step 4: estimation of survivorship probabilities from birth. Estimation of this probability, $l(n)$, the true core of the procedure, is straightforward enough once the mean age at maternity, M, and appropriate estimates of $l_f(2)$ have been obtained. It involves only substitution in equation (C.1) using the coefficients given in table 107. Care must be taken to match correctly these coefficients with the proportions with surviving mother, $S(n)$, for different values of n. It is also necessary at this point to calculate the value of the standard ratio, RS, which is the probability of survival from age 2 to age 25 in the female level 16 life table of the Coale-Demeny family that best represents the population being studied. That value is

$$RS = l_s(25)/l_s(2). \qquad \text{(C.2)}$$

For convenience, the four values of RS associated with the Coale-Demeny models are shown in table 108. The user must select the appropriate model and then use the corresponding value of RS as input for equation (C.1). Note that the use of other standards, though not covered by the model cases, would not result in major biases, as long as RS is calculated for the standard being used.

TABLE 108. STANDARD RATIO VALUES TO BE USED IN ESTIMATION OF SURVIVORSHIP PROBABILITIES FROM BIRTH ON THE BASIS OF DATA ON MATERNAL ORPHANHOOD, COALE-DEMENY MODELS

Coale-Demeny family of model life tables (1)	*Standard ratio* $RS = l_f(25)/l_f(2)$ (2)
North	0.90198
South	0.92581
East	0.93568
West	0.92346

(d) *A detailed example*

To compare the performance of the different methods of adult mortality estimation, the case of Bolivia presented in subsection B.2 (b) (iii) is again used. The raw data collected by the National Demographic Survey in 1974 are shown in table 89. Data on female children ever born and surviving are given below in table 109; results are summarized in table 110.

TABLE 109. FEMALE CHILDREN EVER BORN AND SURVIVING ACCORDING TO THE NATIONAL DEMOGRAPHIC SURVEY, BOLIVIA, 1975

Age group (1)	*Total number of women* (2)	*Number of daughters* — *Ever born* (3)	*Surviving* (4)
15-19	3 069	170	150
20-24	2 404	1 175	974
25-29	1 932	2 343	1 867
30-34	1 469	2 857	2 200
35-39	1 619	4 213	3 149
40-44	1 192	3 447	2 596
45-49	1 281	3 771	2 742

TABLE 110. ESTIMATION OF CHILD MORTALITY FOR FEMALES, BOLIVIA, 1975

Age group of mother (1)	*Age* x (2)	*Probability of dying* $q_f(x)$ (3)	*West mortality level* (4)	*Reference date* (5)
20-24	2	0.1863	11.04	1973.5
25-29	3	0.2080	10.87	1971.8
30-34	5	0.2360	10.58	1969.7
35-39	10	0.2631	10.37	1967.3
40-44	15	0.2541	11.35	1964.6
45-49	20	0.2787	11.20	1961.6

The steps of the procedure are given below.

Step 1: calculation of mean age at maternity. Reference should be made to the first step in subsection B.2 (b) (iii), where the mean age at maternity, M, was calculated in detail for Bolivian females. Its value was found to equal 28.8 years.

Step 2: calculation of reference periods of the conditional survivorship probabilities estimated from information on maternal orphanhood. This step is identical to that presented as step 3 in subsection B.2 (c) (iii). Therefore, it is not repeated here. However, the reference dates estimated there (see table 95) are again given in column (3) of table 111 for immediate reference.

Step 3: estimation of probability of surviving from birth to age 2 for females. The data on female children ever born

TABLE 111. ESTIMATION OF FEMALE SURVIVORSHIP PROBABILITIES FROM BIRTH USING INFORMATION ON ORPHANHOOD BY AGE OF RESPONDENT, BOLIVIA, 1975

Age group (1)	*Proportion with mother surviving* $S(n-5)$ (2)	*Reference date* (3)	*West level for* $l_f(2)$ (4)	*Probability of surviving to age 2* $l_f(2)$ (5)	*Age* n (6)	*Female adult survivorship probability* $l_f(25+n)$ (7)	*West level for* $l_f(25+n)$ (8)
15-19	0.9252	1967.9	10.4	0.8012	20	0.6692	13.9
20-24	0.8807	1966.1	10.2	0.7973	25	0.6410	14.1
25-29	0.7896	1964.5	10.1	0.7954	30	0.5752	13.4
30-34	0.6915	1963.1	9.9	0.7913	35	0.5098	13.1
35-39	0.5737	1961.8	9.8	0.7893	40	0.4318	12.9
40-44	0.4467	1960.7	9.7	0.7872	45	0.3407	12.8
45-49	0.3546	1960.4	9.6	0.7851	50	0.2774	14.1

and surviving, given in table 109, were gathered by the National Demographic Survey of Bolivia in 1975. This is the first such data set available for the country, as questions on this subject had not been asked previously. As explained in chapter III, these data can be used to obtain an estimate of $l_f(2)$, the probability of surviving from birth to age 2, for females. The procedure followed is that described in subsection B.2 of chapter III and its detailed application is not presented here. For the purpose at hand it suffices to consider the results obtained. Table 110 summarizes these results. The usual estimates of the probability of dying, $q_f(x)$, yielded by the method are listed in column (3); column (4) shows the mortality levels consistent with the estimated $q_f(x)$ estimates in the West family of Coale-Demeny model life tables, while column (5) shows the reference date of each estimate (obtained by subtracting each reference period value, $t(i)$, for the child mortality estimates, from 1975.6, the reference date for the 1975 survey).

Two characteristics of the child mortality estimates given in table 110 should be pointed out. First, the estimates corresponding to the earliest periods are derived from data for women aged 40-44 and 45-49 at the time of the survey; and, secondly, these estimates are precisely those which do not follow, in terms of mortality levels, the trend implied by the others. Given the most common flaws of data on children ever born and surviving (see chapter III, subsection A.1), it is likely that the estimates referring to 1961.6 and 1964.6 may be too high (in terms of mortality levels) because of the tendency of older women to omit some of their dead children. Such doubts about the quality of these estimates do not recommend them for use in other estimation procedures.

Unfortunately, as the reference dates listed in column (3) of table 111 show, most of the conditional survivorship estimates derived from data on maternal orphanhood refer to the period 1960-1965, so that child mortality estimates for the same period are desirable. In order to obtain such estimates, the trend implied by the $q_f(2)$, $q_f(3)$, $q_f(5)$ and $q_f(10)$ estimates given in table 110 is extrapolated into the past. There are many possible ways of extrapolating this trend, but the simplest was selected, mainly because the use of more sophisticated techniques is not warranted by the approximate nature of the timing estimates.

A plot of the first four mortality levels against time would show that they define a fairly linear trend. Therefore, using the first and fourth to determine the trend line, its slope (change in level per annum) is calculated as

$$\Theta = (11.04-10.37)/(1973.5-1967.3) = 0.108$$

so that, for 1960.7, for example, the extrapolated mortality level is

$$10.37+0.108(1960.7-1967.3) = 9.7.$$

The complete set of West mortality levels as defined by these extrapolated child mortality estimates and corresponding to the periods to which the orphanhood-based estimates refer is shown in column (4) of table 111. Column (5) shows the $l_f(2)$ values that these estimates imply. These values were obtained by interpolating linearly between the $l(2)$ values listed in table 236 (see annex VIII). For example, for the estimated level of 9.7 obtained above, the $l_f(2)$ value lies between that corresponding to level 9 (0.77271) and that corresponding to level 10 (0.79340). Using linear interpolation (see annex IV), the desired $l_f(2)$ for level 9.7 is calculated as follows:

$$l_f(2) = 0.3(0.77271)+0.7(0.79340) = 0.7872.$$

Step 4: estimation of survivorship probabilities from birth. Using the values of M and $l_f(2)$ given above and the values for RS for model West given in table 108, the final step in this procedure is rather simple. Essentially, for each value of n, substitution of the values of M, $l_f(2)$, $S(n-5)$ and RS in equation (C.1) is carried out, using the coefficients given in table 107. Column (7) of table 111 shows the estimates of $l_f(25+n)$ obtained in this way. As an example, $l(50)$ and $l(60)$ are calculated below in detail:

$$\begin{aligned} l_f(50) &= -1.2508+0.0051(28.8)+ \\ &\quad 1.1934(0.7973)(0.8807)+0.9821(0.92346) \\ &= 0.6410; \\ l_f(60) &= -1.2669+0.0115(28.8)+ \\ &\quad 1.1423(0.7913)(0.6915)+0.8885(0.92346) \\ &= 0.5098. \end{aligned}$$

Note that because different estimates of $l_f(2)$ are available for each time period, the values of this variable also changes with n, while that of RS remains constant throughout.

In order to assess the estimated probabilities of survival from birth to adult ages, the West mortality levels consistent with them were calculated. Again, this calculation involves linear interpolation between the values listed in table 236 in annex VIII. Note that because the estimated values are probabilities of survival from birth, the life-table values themselves are used as the basis of interpolation (that is, no special tabulations of the life tables are needed). As an example, the level consistent with $l_f(60) = 0.5098$ is found by identifying those values in the columns labelled "$l(60)$" of table 236 (see annex VIII) which enclose the observed value. In this case, the enclosing values are 0.50587 and 0.54215, corresponding to levels 13 and 14, respectively. Hence, the level corresponding to 0.5098 is

$$13.0+(0.50980-0.50587)/(0.54215-0.50587) = 13.1.$$

The set of levels given in column (8) of table 111 shows that the estimates from $l_f(55)$ to $l_f(70)$ are fairly consistent, implying similar mortality levels and a plausible trend of decline. The levels associated with $l_f(45)$, $l_f(50)$ and $l_f(75)$ are rather high and out of line with the others, so they need to be interpreted with caution.

At this point, it is worth comparing these estimates with those obtained earlier using the conditional methods. Refer, for example, to table 95, where the mortality levels displayed refer to the same periods as those shown in table 111. Note that the use of a child mortality indicator in the estimation process has had the effect of lowering substantially the adult mortality levels implied by the orphanhood data (table 111). The large difference between the levels given in table 95 (determined mainly by information on maternal orphanhood) and those presented in table 110 (determined by the data on child survivorship) implies one or more of three possibilities: that model West is not a good representation of the mortality pattern of the female population of Bolivia; that orphanhood is underreported, leading to underestimates of adult mortality; or that child survivorship is underreported and the child mortality estimates obtained are too high. Although the evidence presented here is not sufficient to decide among these three possibilities or between different combinations of them, other evidence suggests that maternal orphanhood in Bolivia was indeed underreported and that the estimated mortality levels presented in table 95 are too high. In this case, therefore, it seems that the estimates shown in table 111 are more acceptable, mainly because they are determined to a considerable extent by the child mortality estimates they incorporate.

3. *Estimation of survivorship from birth to adult ages on the basis of proportions not widowed*

(a) *Basis of method and its rationale*

The methods discussed below are an extension of those presented in subsection B.3. Once more, data on proportions with surviving first spouse, tabulated either by the age or the duration of first marriage of the respondent, are used to estimate survival probabilities. In the present case, however, the incorporation of some information on the level of mortality prevalent at younger ages (in the form of estimates of $l(2)$) allows the estimation of probabilities of survival from birth in a way that parallels the method just described (see subsection C.2), which uses data on survival of mother to estimate survivorship probabilities from birth.

Both the age and duration methods that are presented here use as input an estimate of $l(2)$ (the probability of survival from birth to age 2) for the sex whose survivorship probabilities are to be estimated. An estimate of $l(2)$ is usually obtained from responses to questions regarding children ever born and children surviving. Methods used in carrying out this estimation are described in chapter III. If an estimate of $l(2)$ is available only for both sexes combined, suitable estimates for each sex can be obtained by assuming that the sex differentials embodied in the Coale-Demeny model life tables are an adequate representation of those prevalent in the population being considered. As in the orphanhood case, the explicit use of $l(2)$ coupled with the derivation of estimation equations from data generated under the assumption of constant mortality further complicates the determination of the time location to which the estimates refer. When there is evidence supporting the existence of a mortality change, appropriate $l(2)$ values should be calculated for each of the periods to which the conditional survivorship estimates derived from widowhood data refer, in order to ensure that the survival probabilities from birth estimated according to the method described here shall also refer to well-defined periods.

(b) *Widowhood data classified by age*

An equation relating the value of probabilities of survival from birth to the values of the singulate mean ages at marriage for males and females, the value of $l(2)$ (the probability of surviving from birth to exact age 2), the proportion with surviving first spouse and an indicator of the relationship between child and adult mortality, *RSW*, was fitted by least-squares regression to data from 900 simulated cases. These cases were generated using model nuptiality, fertility and mortality schedules. The mortality schedules were obtained from the logit system using female level 16 model life tables from each of the four Coale-Demeny families as standards (see chapter I, subsections B.2 and B.4), while the nuptiality and fertility schedules were derived from the models proposed by Coale and McNeil[17] and Coale and Trussell,[18] respectively (see chapter I, section D and subsection E.1). The simulation carried out also makes some allowance for the age distribution at first marriage of spouses according to the age group to which the respondent belonged at the time of first marriage.

The equations used to estimate the probabilities of surviving to adult ages have very similar forms:

$$l_m(n) = a(n) + b(n)\,SMAM_f + c(n)\,SMAM_m + d(n)\,NW_f(n-5) + e(n)\,l_m(2) + f(n)\,RSW$$

$$l_f(n) = a(n) + b(n)\,SMAM_f + c(n)\,SMAM_m + d(n)\,NW_m(n) + e(n)\,l_f(2) + f(n)\,RSW \quad \text{(C.3)}$$

where $a(n)$, $b(n)$, $c(n)$, $d(n)$, $e(n)$ and $f(n)$ are coefficients that depend both upon sex and upon age; $SMAM_f$ and $SMAM_m$ are the singulate mean ages at marriage for females and males, respectively; $NW(n)$ is the proportion of ever-married respondents aged from n to $n+4$ whose first spouse was alive at the time of the interview; $l(2)$ is the probability of surviving from birth to age 2 for the spouses; and *RSW* is the ratio of $l(20)$ and $l(2)$ in the standard (the female level 16 model life table from the Coale-Demeny family that best approxi-

[17] Ansley J. Coale and Donald R. McNeil, "The distribution by age of the frequency of first marriage in a female cohort", *Journal of the American Statistical Association*, vol. 67, No. 340 (December 1972), pp. 743-749.

[18] A. J. Coale and T. J. Trussell, *loc. cit.*

mates the pattern of the mortality experienced by the population in question). Note that although the model cases were based on Coale-Demeny standards, the use of other standards, with their implied values of *RSW*, should not result in important biases.

Table 112 shows the values of the coefficients that are to be used in estimating male adult mortality. Note that in this case the value of $l(2)$ appearing in equation (C.3) should be the probability of surviving from birth to age 2 for males, while $NW(n)$ should be the proportion of ever-married female respondents whose first husbands were alive at the time of the interview. The *RSW* values listed in table 114 were calculated for female level 16 life tables from the Coale-Demeny families because it was those life tables which were used as standards when generating the simulated cases. If some other standard is regarded as more suitable, its *RSW* value should be calculated and used in equation (C.3).

The values of the coefficients that are to be used in estimating female mortality are shown in table 113. When these values are used, $l(2)$ should refer to females and $NW(n)$ should be the proportion of male respondents aged from n to $n+4$ whose first wives were alive at the time of the interview. *RSW* is again selected from the values listed in table 114 or calculated especially if some other standard is to be used.

TABLE 112. COEFFICIENTS FOR ESTIMATION OF MALE SURVIVORSHIP FROM BIRTH FROM PROPORTIONS OF WOMEN WITH SURVIVING FIRST HUSBAND, CLASSIFIED BY AGE

Age n (1)	Coefficients $a(n)$ (2)	$b(n)$ (3)	$c(n)$ (4)	$d(n)$ (5)	$e(n)$ (6)	$f(n)$ (7)
25	−3.0441	−0.00364	0.00125	1.5870	1.1666	1.3952
30	−2.6765	−0.00595	0.00201	1.3842	1.1140	1.3032
35	−2.3864	−0.00708	0.00281	1.2018	1.0668	1.2386
40	−2.1933	−0.00795	0.00401	1.0747	1.0230	1.1979
45	−2.0988	−0.00906	0.00581	0.9814	0.9805	1.2138
50	−2.0299	−0.01084	0.00844	0.9253	0.9267	1.2236
55	−1.9541	−0.01347	0.01203	0.8993	0.8550	1.2094
60	−1.8377	−0.01704	0.01651	0.9037	0.7581	1.1505

Estimation equation:

$$l_m(n) = a(n) + b(n)\,SMAM_f + c(n)\,SMAM_m + d(n)NW_f(n-5) + e(n)l_m(2) + f(n)\,RSW$$

TABLE 113. COEFFICIENTS FOR ESTIMATION OF FEMALE SURVIVORSHIP FROM BIRTH FROM PROPORTIONS OF MEN WITH SURVIVING FIRST WIFE, CLASSIFIED BY AGE

Age n (1)	Coefficients $a(n)$ (2)	$b(n)$ (3)	$c(n)$ (4)	$d(n)$ (5)	$e(n)$ (6)	$f(n)$ (7)
25	−3.3410	0.00099	−0.00262	1.9929	1.1399	1.3161
30	−2.9062	0.00137	−0.00432	1.6824	1.1019	1.2615
35	−2.5558	0.00183	−0.00556	1.4558	1.0565	1.1989
40	−2.2860	0.00242	−0.00641	1.2837	1.0138	1.1456
45	−2.1048	0.00327	−0.00713	1.1534	0.9732	1.1290
50	−1.9431	0.00461	−0.00790	1.0648	0.9220	1.0890
55	−1.7821	0.00666	−0.00906	1.0044	0.8577	1.0267

Estimation equation:

$$l_f(n) = a(n) + b(n)\,SMAM_f + c(n)\,SMAM_m + d(n)NW_m(n) + e(n)l_f(2) + f(n)\,RSW$$

TABLE 114. VALUES OF THE STANDARD RATIO, *RSW*, INDICATING THE RELATIONSHIP BETWEEN CHILD AND ADULT MORTALITY IN ESTIMATION OF SURVIVORSHIP PROBABILITIES FROM BIRTH ON THE BASIS OF WIDOWHOOD DATA, COALE-DEMENY MODELS

Coale-Demeny family of model life tables (1)	Standard ratio $RSW = l_f(20)/l_f(2)$ (2)
North	0.91932
South	0.94010
East	0.95022
West	0.94181

(i) *Data required*

The following data are required for this method:

(a) the proportions of ever-married male (female) respondents whose first spouses were alive at the time of the interview, classified by five-year age groups from n to $n+4$. These proportions are denoted by $NW(n)$. See subsection B.3 (b) (i) for a discussion of the type of raw input data necessary to calculate them;

(b) Proportions single classified by five-year age group and by sex. This information is needed to compute the singulate mean age at marriage, *SMAM*, for each sex (see annex I);

(c) Information on children ever born and surviving, by sex of child and by five-year age or marriage duration group of mother (the classification by sex is useful but not essential). This information is used to estimate $l(2)$ by using the methods described in chapter III.

(ii) *Computational procedure*

The steps of the computational procedure are described below.

Step 1: calculation of singulate mean ages at marriage for males and females. A detailed description of the procedures followed in calculating these parameters is presented in annex I.

Step 2: calculation of reference periods for conditional survivorship probabilities obtained from information on widowhood status. This step is identical to that presented as step 3 in subsection B.3 (b) (ii). Therefore, its description is not repeated here.

Step 3: estimation of probability of surviving from birth to age 2. These methods are described in chapter III. Ideally, estimates of the probability of surviving to age 2, $l(2)$, should be obtained for each of the reference periods estimated in step 2. The $l(2)$ estimates are necessary only for the sex of the respondents' spouses. If data on child survivorship are not available by sex, models can be used to approximate acceptable sex differentials.

Step 4: estimation of survivorship probabilities from birth. Estimation of these probabilities, $l(n)$, is carried out by substituting into equation (C.3) the *SMAM* and $l(2)$ values computed in the previous steps, as well as the proportions not widowed, the selected *RSW* value from table 114 and the appropriate coefficients taken from tables 112 or 113. It is important to keep in mind that when male adult mortality is being estimated, $l(2)$ values for males must be used, while $NW(n)$ should be the proportion of female respondents not widowed. In contrast, when female mortality is being estimated, the respondents are male and values of $l(2)$ for females must be used.

(iii) *A detailed example*

The use of this method is illustrated by estimating female probabilities of survival from birth for Bolivia from data on the incidence of widowhood among male respondents. The data used were collected by the National Demographic Survey carried out in Bolivia during 1975. Columns (3) and (4) of table 115 show, respectively, the number of ever-married male respondents with first wife still alive and the number whose first wife was dead, classified by five-year age group. The denominators needed to calculate the proportions of respondents with surviving first wife for each age group are the sum of these two quantities, thus eliminating cases of non-response from both numerator and denominator; they are shown in column (5) under the heading "ever-married male population". Column (6) shows the required proportions of those not widowed, computed by dividing the entries in column (3) by those in column (5). For example, $NW_m(30)$ is calculated as follows:

$$NW_m(30) = 1{,}088/(1{,}088+39) = 1{,}088/1{,}127 = 0.9654.$$

Step 1: calculation of singulate mean ages at marriage for males and females. The values of the singulate mean ages at marriage have already been presented in subsection B.3 (b) (iii). They are: $SMAM_m = 25.3$; and $SMAM_f = 23.2$.

Step 2: calculation of reference periods of conditional survivorship probabilities obtained from information on widowhood status. Using equations (B.19) and (B.20), the reference periods for the conditional probabilities of female survival calculated from the proportions of male respondents with first wife alive are estimated. Table 116 shows several intermediate results and the final reference-period estimates both in terms of years before the survey, denoted by $t_f(n)$, and in terms of actual dates (decimal equivalents in terms of years). The dates are calculated by subtracting each $t_f(n)$ from 1975.6, the reference date of the survey. The West mortality levels consistent with each of the conditional survivorship probabilities are also shown for future reference. No detailed example of the calculation of $t_f(n)$ is presented here because such an example has already been given for the case of the estimation of male adult mortality in step 4 in subsection B.3 (b) (iii).

Step 3: estimation of probability of surviving from birth to age 2 for females. Since the process of estimating this probability, $l_f(2)$, for Bolivian females has already been described in step 3 in subsection C.2 (d), the reader is referred to that section for a discussion of the procedure for selecting a trend line defining changes in child mortality. In this case, the same trend line is used to estimate the West mortality levels prevalent during the more recent period to which the conditional survivorship

TABLE 115. DATA ON WIDOWHOOD STATUS OF MALES OBTAINED IN NATIONAL DEMOGRAPHIC SURVEY, BOLIVIA, 1975

Age group (1)	Age n (2)	Number of respondents: Not widowed (3)	Number of respondents: Widowed (4)	Ever-married male population (5)	Proportion not widowed $NW_m(n)$ (6)
20-24	20	713	5	718	0.9930
25-29	25	1 208	22	1 230	0.9821
30-34	30	1 088	39	1 127	0.9654
35-39	35	1 154	54	1 208	0.9553
40-44	40	980	77	1 057	0.9272
45-49	45	1 000	98	1 098	0.9107
50-54	50	651	92	743	0.8762
55-59	55	452	107	559	0.8086

TABLE 116. ESTIMATION OF TIME REFERENCE PERIODS FOR THE CONDITIONAL SURVIVORSHIP PROBABILITIES FOR FEMALES, BOLIVIA, 1975

Age n *(1)*	*Proportion not widowed* $NW_m(n)$ *(2)*	*Length of exposure indicator* $x_f(n)$ *(3)*	*Standard function* $Z_f(n)$ *(4)*	*Correction function* $u_f(n)$ *(5)*	*Reference period*[a] $t_f(n)$ *(6)*	*Reference date* *(7)*	*Conditional female survivorship probability* $l_f(n)/l_f(20)$ *(8)*	*West mortality level* *(9)*
25.............	0.9821	25.4	0.090	0.0899	1.0	1974.6	0.9830	16.8
30.............	0.9654	30.4	0.090	0.0923	3.3	1972.3	0.9622	16.6
35.............	0.9553	35.4	0.091	0.0898	5.6	1970.0	0.9543	18.2
40.............	0.9272	40.4	0.106	0.0949	7.8	1967.8	0.9253	17.5
45.............	0.9107	45.4	0.143	0.1259	9.7	1965.9	0.9132	18.4
50.............	0.8762	50.4	0.198	0.1680	11.3	1964.3	0.8817	18.3
55.............	0.8086	55.4	0.265	0.2083	12.7	1962.9	0.8155	17.1

[a] Number of years prior to the survey to which survivorship estimates refer.

probabilities derived from widowhood refer. The estimated levels are shown in column (5) of table 117, and the $l_f(2)$ values associated with them are given in column (6).

Step 4: estimation of female survivorship probabilities from birth. Using the coefficients given in table 113, the estimates of female survivorship probabilities from birth, $l_f(n)$, are calculated by substituting the values of *SMAM* obtained in step 1, the $l_f(2)$ values obtained in step 3, the values of $NW_m(n)$ and the value of *RSW* corresponding to the West standard (female level 16) in equation (C.3). The value of *RSW* is taken from table 114 and is equal to 0.94181. As an example, $l_f(35)$ is calculated below:

$$l_f(35) = -2.5558 + 0.00183(23.2) - 0.00556(25.3)$$
$$+ 1.4558(0.9553) + 1.0565(0.8071)$$
$$+ 1.1989(0.94181)$$
$$= 0.7186.$$

Column (7) of table 117 shows the complete set of $l_f(n)$ estimates and column (8) shows the levels they imply in the West family of Coale-Demeny model life tables (obtained by interpolating linearly between the values shown in table 236 in annex VIII).

A comparison of these mortality levels with those presented in table 116 indicates that the estimates of conditional probabilities of survivorship associated with the latter imply substantially lower mortality (that is, higher levels) than that implied by the $l_f(n)$ values obtained by taking into account child mortality. The immediate reason for this difference is that the child mortality estimates employed imply very high mortality (that is, low levels); and hence, their use in the calculation of $l_f(n)$ reduces the mortality levels associated with the latter. As in the case of the data on orphanhood, the existence of such differences implies one or more of three possibilities: that the West model does not adequately represent the age pattern of mortality in Bolivia, that child mortality is overestimated or that male respondents overreport the survivorship of their first wives. Although the evidence presented here does not permit us to establish which of these mechanisms is in operation, a more comprehensive analysis of Bolivian data indicates that the information on male widowhood severely underestimates mortality. The weakness of the widowhood data in this particular case is also suggested by the fact that the mortality levels associated both with the conditional survivorship probabilities and with those estimated from birth (columns (9) and (8) of tables 116 and 117, respectively) fail to increase as age of respondent decreases (that is, as one moves towards the present in terms of reference dates). Taken at face value, these estimates would imply that female adult mortality in Bolivia has increased through time. The small likelihood of such an event immediately makes their accuracy questionable, but it is the comparison between

TABLE 117. ESTIMATION OF FEMALE SURVIVORSHIP FROM BIRTH USING DATA ON MALE WIDOWHOOD STATUS, BOLIVIA, 1975

Age group *(1)*	*Age* n *(2)*	*Proportion not widowed* $NW_m(n)$ *(3)*	*Reference date* *(4)*	*West level for* $l_f(2)$ *(5)*	*Probability of surviving to age 2* $l_f(2)$ *(6)*	*Female survivorship from birth* $l_f(n)$ *(7)*	*West level for* $l_f(n)$ *(8)*
25-29........	25	0.9821	1974.6	11.2	0.8167	0.7434	12.8
30-34........	30	0.9654	1972.3	10.9	0.8110	0.7222	13.0
35-39........	35	0.9553	1970.0	10.7	0.8071	0.7186	13.7
40-44........	40	0.9272	1967.8	10.4	0.8012	0.6894	13.7
45-49........	45	0.9107	1965.9	10.2	0.7973	0.6803	14.3
50-54........	50	0.8762	1964.3	10.0	0.7934	0.6541	14.4
55-59........	55	0.8086	1962.9	9.9	0.7913	0.6010	14.1

these levels and those implied by the estimates of child mortality that best illustrates the inconsistencies in the data. Hence, the Bolivian case is a good example of how the application of a variety of estimation methods allows the assessment of data quality.

(c) *Widowhood data classified by duration of marriage*

When the proportion of ever-married respondents whose first spouse is alive is tabulated by sex and by the time elapsed since their first union or marriage (in the broadest sense of this term) the estimation of $l(n)$ becomes somewhat simpler since the period of exposure to the risk of dying is directly known and does not need to be estimated from information on age. This simplification allows the set of independent variables used as predictors of $l(n)$ in equation (C.3) to be reduced. Thus, when male mortality is to be estimated from the proportion of females not widowed whose first marriage took place between k and $k+4$ years ago, denoted by $NW_f(k)$, the equivalent of equation (C.3) becomes

$$l_m(n)=a(n)+b(n)\,l_m(2)+c(n)\,NW_f(n-20)+d(n)\,SMAM_m \qquad \text{(C.4)}$$

where $l_m(2)$ is the probability of surviving from birth to exact age 2 years among males; $SMAM_m$ is the male singulate mean age at marriage; and $NW_f(n-20)$ is the proportion of female respondents whose first marriages occurred between $n-20$ and $n-16$ years before the interview and whose first husbands were still alive at the time of the interview. The equation to be used to estimate female mortality is

$$l_f(n)=a(n)+b(n)\,l_f(2)+c(n)\,NW_m(n-20)+d(n)\,SMAM_f \qquad \text{(C.5)}$$

where $SMAM_f$ is the female singulate mean age at marriage; $NW_m(n-20)$ is now the proportion of male respondents whose first wives were alive at the time of the interview and whose first marriages occurred between $n-20$ and $n-16$ years before the interview; and $l_f(2)$ is the probability of surviving from birth to age 2 for females.

In both cases, $a(n)$, $b(n)$, $c(n)$ and $d(n)$ stand for the values of coefficients obtained by using least-squares regression to fit equations (C.4) and (C.5) to simulated cases. Their values are listed in tables 118 and 119. Table 118 refers to male mortality and the values listed in it should be used in conjunction with equation (C.4), while table 119 refers to female mortality and its values should be used with equation (C.5).

Even though this method is simpler, from a theoretical standpoint, than that using data on widowhood status classified by age, it may, in practice, produce poorer results than the latter method in countries where a sizeable proportion of the ever-married population live in consensual unions rather than in formal marriages because, in this case, it may be difficult for many respondents to establish unambiguously the date on which their first union began. In particular, members of relatively unstable unions may have a tendency to report the survival of the current partner rather than that of the first, a phenomenon that would reduce artificially the observed proportions widowed.

A problem that the duration-based method shares

TABLE 118. COEFFICIENTS FOR ESTIMATION OF MALE SURVIVORSHIP FROM BIRTH FROM PROPORTIONS OF WOMEN WITH SURVIVING FIRST HUSBAND, CLASSIFIED BY DURATION OF FIRST MARRIAGE

Age n (1)	Duration group (2)	Coefficients $a(n)$ (3)	$b(n)$ (4)	$c(n)$ (5)	$d(n)$ (6)
20.............	0-4	−3.4875	0.9607	3.4884	0.00077
25.............	5-9	−1.5427	0.9387	1.5458	0.00131
30.............	10-14	−1.1558	0.9165	1.1521	0.00224
35.............	15-19	−0.9867	0.8942	0.9703	0.00346
40.............	20-24	−0.8978	0.8703	0.8638	0.00499

Estimation equation:
$l_m(n)=a(n)+b(n)\,l_m(2)+c(n)\,NW_f(n-20)+d(n)\,SMAM_m$

TABLE 119. COEFFICIENTS FOR ESTIMATION OF FEMALE SURVIVORSHIP FROM BIRTH FROM PROPORTIONS OF MEN WITH SURVIVING FIRST WIFE, CLASSIFIED BY DURATION OF FIRST MARRIAGE

Age n (1)	Duration group (2)	Coefficients $a(n)$ (3)	$b(n)$ (4)	$c(n)$ (5)	$d(n)$ (6)
20.............	0-4	−4.0224	0.9386	4.0102	0.00263
25.............	5-9	−1.6857	0.9083	1.7107	0.00189
30.............	10-14	−1.2271	0.8801	1.2701	0.00203
35.............	15-19	−1.0284	0.8519	1.0780	0.00277
40.............	20-24	−0.9168	0.8212	0.9675	0.00392

Estimation equation:
$l_f(n)=a(n)+b(n)\,l_f(2)+c(n)\,NW_m(n-20)+d(n)\,SMAM_f$

with that based on data classified by age is that the coefficients presented in tables 118 and 119 were derived from cases simulated under the assumption of constant mortality. When mortality has been changing, the estimates of survivorship derived exclusively from the proportions of respondents with first spouse alive will, in general, refer to different time periods. As discussed in subsection C.3 (a), estimates of $l(2)$ for the same reference periods as the conditional survivorship probabilities that may be estimated from the proportions with surviving first spouse should be used in equations (C.4) and (C.5)

With respect to the reference period of the estimates derived from widowhood information, the duration version of these estimation methods has an advantage over the age version when widowhood data classified by duration of first marriage are available from two surveys five or 10 years apart. In this case, proportions not widowed for a hypothetical intersurvey marriage cohort can be constructed following the procedure described for orphanhood data in subsection B.2 (d), and $l(n)$ estimates referring specifically to the intersurvey period can be obtained directly from equations (C.4) and (C.5) by using as input estimates of $l(2)$ obtained either for another hypothetical intersurvey cohort (see chapter III, section D) or from the second survey and referring roughly to the intersurvey period, and the values of *SMAM*, referring also to the intersurvey period. A hypothetical-cohort approach to the calculation of *SMAM* is feasible, as is shown in annex I, although, unless nuptiality patterns are changing very rapidly, the use of the *SMAM* estimates obtained from either survey or of the average of both should be acceptable.

(i) *Data required*

In order to estimate male (female) survivorship probabilities, the following data are needed:

(*a*) Estimates of $l(2)$, the probability of surviving from birth to age 2 for males (females), for different time periods. These estimates are usually obtained from information on children ever born and surviving by using the methods described in chapter III;

(*b*) The singulate mean age at marriage for males (females). Refer to annex I for a description of how to calculate this parameter;

(*c*) The proportion of female (male) ever-married respondents whose first spouses were alive at the time of the interview, classified by duration of marriage (strictly speaking, classification should be according to the time elapsed since their first union). See subsection B.3 (c) (i) for a discussion of the possible types of data from which these proportions may be calculated.

(ii) *Computational procedure*

The steps of the computational procedure are described below.

Step 1: calculation of singulate mean age at marriage for spouses of respondents. Refer to annex I for a detailed description of the procedure to be followed in calculating this parameter.

Step 2: calculation of reference periods of conditional survivorship probabilities obtained from information on widowhood status. This step is identical to that presented as step 4 in subsection B.3 (c) (ii). Therefore, its description is not repeated here.

Step 3: estimation of probability of surviving to age 2 for sex of the spouses of respondents. Reference should be made to the methods described in chapter III. Ideally, these probabilities, denoted by $l(2)$, should be obtained for each of the reference periods estimated in step 2. These estimated probabilities are required only for the sex of the respondents' spouses. When data on child mortality by sex are not available, models can be used to approximate adequate sex differentials.

Step. 4: estimation of survivorship probabilities from birth. Estimation of survivorship probabilities, $l(n)$, is carried out by substituting in equation (C.4) or (C.5), depending upon the sex of respondents, the *SMAM* and $l(2)$ values obtained in previous steps, the observed proportions of respondents with first spouse alive, $NW(n)$, and the appropriate coefficients. It is important to match the proportions $NW(n)$ determining a survivorship estimate for a certain period with the $l(2)$ value referring to the same period.

(iii) *A detailed example*

As an example of the estimation of adult mortality using information on the proportion of respondents whose first spouse was alive at the time of the interview, classified by duration of marriage, the case of Panama is again used. In this case, the question on widowhood was asked of both men and women during the Demographic Survey in 1976. The answers obtained were tabulated by duration of first union and have already been presented for male respondents in table 104. The number of respondents of known duration who do not know whether their first wife is alive or dead is, in most instances, rather small; and they are excluded from both numerator and denominator in calculating the proportions not widowed. As mentioned in subsection B.3 (c) (iii), however, these data contain a substantial number of cases of unknown marital duration. The problem posed by these cases of unknown duration cannot be dealt with so easily, and the reader is referred to the discussion in subsection B.3 (c) (iii). In this example, the proportions of male respondents whose first wives were alive at the time of the interview, shown in column (3) of table 120, have been calculated, excluding the cases of unknown duration entirely.

The computational procedure entails the following steps.

Step 1: calculation of singulate mean age at marriage for females. According to the survey in 1976, the singulate mean age at marriage for females was 21.95 years (see annex I).

Step 2: calculation of reference periods of female survivorship probabilities obtained from information on widowhood status. This step was carried out in detail in subsection B.3 (c) (iii) (step 4), so only the results obtained are quoted here. Column (4) of table 120 shows the reference dates associated with the conditional survivorship

TABLE 120. ESTIMATION OF FEMALE SURVIVORSHIP PROBABILITIES FROM BIRTH USING DATA ON WIDOWHOOD STATUS OF MALE RESPONDENTS, CLASSIFIED BY DURATION OF MARRIAGE, PANAMA, 1976

Duration group (1)	Age n (2)	Proportion not widowed $NW_m(n-20)$ (3)	Reference date (4)	West level for $l_f(2)$ (5)	Probability of surviving to age 2 $l_f(2)$ (6)	Female survivorship probability from birth $l_f(n)$ (7)	West level for $l_f(n)$ (8)
0-4	20	0.9970	1975.6	20.7	0.9621	0.9365	20.2
5-9	25	0.9895	1973.3	20.1	0.9551	0.9160	19.6
10-14	30	0.9794	1971.1	19.5	0.9477	0.8955	19.2
15-19	35	0.9658	1968.9	18.9	0.9401	0.8744	18.9
20-24	40	0.9428	1967.0	18.5	0.9348	0.8491	18.6

probabilities, derived from widowhood information classified by duration of marriage. These dates have been copied from table 106 and indicate the periods for which estimates of female child mortality are needed.

Step 3: estimation of probability of surviving to age 2 for females. In chapter III, two detailed examples using data from the Demographic Survey of Panama in 1976 were presented, one based on data classified by age of mother (subsection B.3) and the other based on data classified by marriage duration (subsection C.3). The estimates yielded by each set are not identical, so a choice has to be made between them. The estimates derived from duration data exhibit, in terms of West mortality levels, a fairly linear trend with respect to time (if the estimate associated with duration group 0-4 is disregarded), and they have the relative advantage of being obtained from the same type of data (classified by duration) as the adult survivorship estimates considered here. Hence, any errors present in one set may be expected to be similar to those present in the other and it may therefore be easier to detect them.

Table 121 shows the West mortality levels consistent with the child mortality estimates derived in chapter III, subsection C.3, together with their reference dates. A graph of these levels against time shows that the values from the second to the fifth follow an acceptably linear trend. Hence, the line defined by the second and fifth values can be used to estimate the levels prevalent during the reference dates of the estimates of survivorship derived from widowhood data (shown in column (4) of table 120). The trend line fitted to the estimated child mortality levels has as its slope:

$$(20.0-18.1)/(1973.0-1965.6)=0.257.$$

Hence, the level corresponding to 1971.1, for example, is

$$18.1+0.257(1971.1-1965.6)=19.5.$$

All other mortality levels shown in column (5) of table 120 are obtained in a similar way; and by interpolation between the $l(2)$ values listed in table 236 in annex VIII, one can obtain the $l_f(2)$ estimates required as input for equation (C.5). The full set of $l_f(2)$ estimates is shown in column (6) of table 120.

TABLE 121. WEST MORTALITY LEVELS IMPLIED BY THE ESTIMATES OF CHILD MORTALITY OBTAINED FROM DATA CLASSIFIED BY DURATION OF MARRIAGE, PANAMA, 1976

Duration group (1)	Reference date (2)	West mortality level (3)
0-4	1975.3	21.3
5-9	1973.0	20.0
10-14	1970.6	19.7
15-19	1968.3	18.9
20-24	1965.6	18.1

Step 4: Estimation of survivorship probabilities from birth for females. The estimation equation to be used in the case of male respondents is (C.5) with $SMAM_f=21.95$, the $l_f(2)$ values obtained from column (6) of table 120, the $NW_m(n-20)$ proportions from column (3) of the same table; and $a(n)$, $b(n)$, $c(n)$ and $d(n)$ from table 119. The use of equation (C.5) is straightforward. Final results are shown in column (7) of table 120. The consistency of the estimates in terms of equivalent mortality levels is impressive, but it should be mentioned that each estimate is, to a large extent, determined by the $l_f(2)$ value used as input, a fact that greatly reduces their range of variation. On the other hand, the influence of $l_f(2)$ is lowest on the mortality estimates for the longer duration groups, for which the mortality estimates are most similar in terms of implied level to those derived from child survival, so the consistency observed cannot be dismissed.