Chapter I

INDICATORS OF MORTALITY IN CHILDHOOD

LIFE TABLES

A life table is the demographer's way of representing the effects of mortality. A complete life table consists of several functions or sets of numbers, each representing a different aspect of the impact of mortality.[1] Table 1 provides an example of a life table. The core of the life table is the set of values shown in column 3 under the heading $1(x)$. Letting x denote age, those values represent the number of survivors by age out of an initial number of births (100,000 in table 1). Thus, according to the life table in table 1, out of 100,000 births, 86,874 persons survive to age 10 and 71,074 to age 50. These ages represent "exact ages", that is, the 71,074 survivors are persons alive at the exact moment at which they reach age 50: they are not a day older or a day younger than exact age 50.

The typical shape of the $1(x)$ function is displayed in the upper panel of figure 1. The number of survivors decreases markedly from birth (exact age 0) to ages 2 and 3 and then declines fairly slowly until around age 60, after which the decline accelerates.

The population for which the effects of mortality are represented by a life table is an example of a cohort. A cohort is a group of persons experiencing the same event during a given period. For instance, all persons marrying in 1974 constitute a marriage cohort. Similarly, all persons born in 1923 are a birth cohort. A life table represents the survivors of a birth cohort. However, the birth cohort represented by most life tables is not a real one, since it would not be possible to complete the life table until all the members of the birth cohort had died. For instance, a life table representing the survivors of the 1923 birth cohort could not be completed until some time around 2013 or 2023. Consequently, demographers resort to hypothetical birth cohorts, that is, cohorts that are a theoretical fabrication and that do not really exist. Thus, a period life table represents the effects of mortality on a hypothetical cohort that is assumed to be subject during its entire life to the mortality conditions prevalent during a given period.

Given the number of survivors of a hypothetical birth cohort by age—the $1(x)$ values—it is easy to calculate the number of deaths occurring from one age to the next.

TABLE 1. EXAMPLE OF A LIFE TABLE

Age x (1)	*n* (2)	$l(x)$ (3)	$_nd_x$ (4)	q_x (5)	$_nL_x$ (6)	$_nm_x$ (7)	e_x (8)
0	1	100 000	8 177	.0818	94 238	.0868	57.50
1	4	91 823	3 781	.0412	357 424	.0106	61.59
5	5	88 041	1 167	.0133	437 289	.0027	60.18
10	5	86 874	894	.0103	432 136	.0021	55.96
15	5	85 980	1 277	.0149	426 708	.0030	51.51
20	5	84 703	1 651	.0195	419 388	.0039	47.25
25	5	83 052	1 858	.0224	410 617	.0045	43.14
30	5	81 194	2 075	.0256	400 784	.0052	39.07
35	5	79 119	2 321	.0293	389 794	.0060	35.03
40	5	76 798	2 624	.0342	377 432	.0070	31.01
45	5	74 175	3 100	.0418	363 122	.0085	27.02
50	5	71 074	4 059	.0571	345 223	.0118	23.09
55	5	67 015	5 250	.0783	321 951	.0163	19.34
60	5	61 765	7 226	.1170	290 761	.0249	15.77
65	5	54 539	9 389	.1722	249 225	.0377	12.53
70	5	45 151	11 799	.2613	196 255	.0601	9.61
75	5	33 352	12 807	.3840	13 474	.0951	7.13
80	20	20 545	20 545	1.0000	102 911	.1996	5.01

Source: Ansley J. Coale and Paul Demeny, *Regional Model Life Tables and Stable Populations* (Princeton, Princeton University Press, 1966, p.17

$l(x)$ number of survivors to exact age x

$_nd_x$ number of deaths between exact ages x and $x + n$

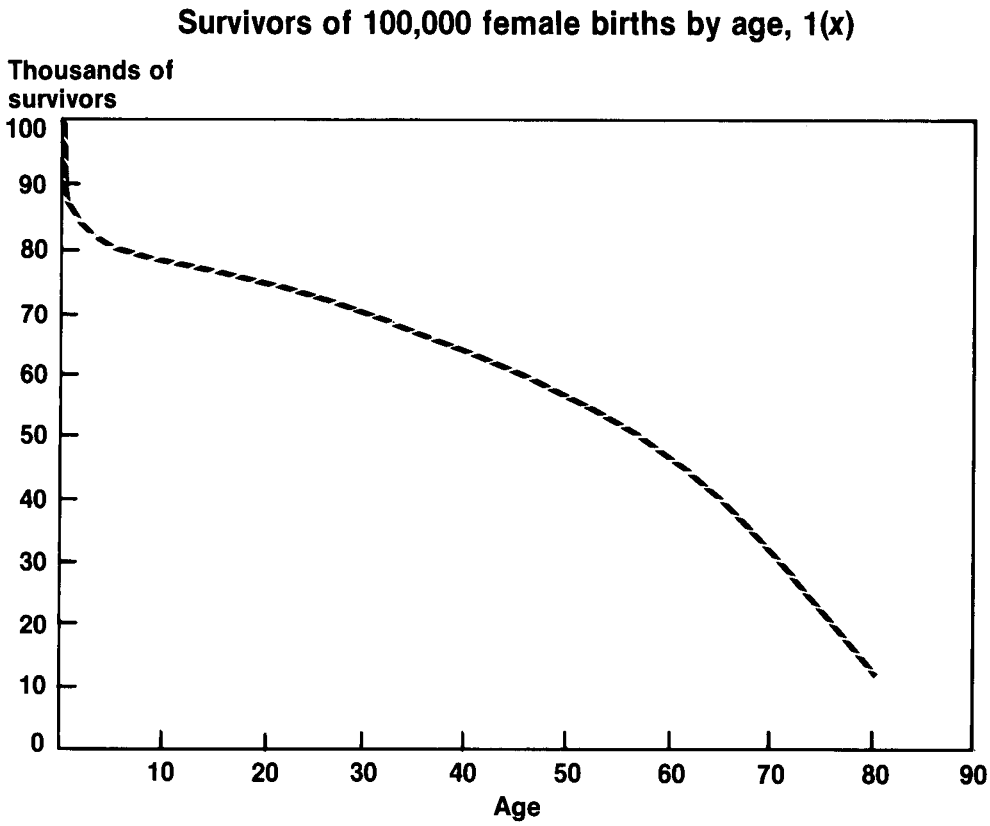
$_nq_x$ probability of dying between exact ages x and $x + n$

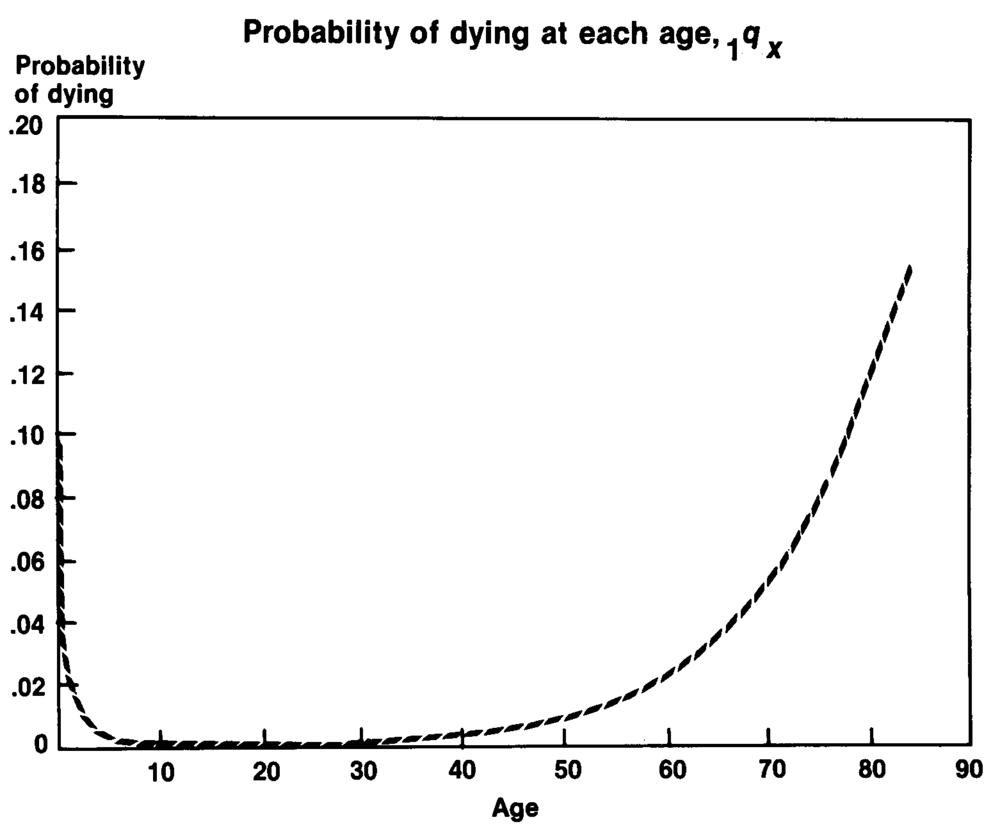
$_nL_x$ number of person-years lived between exact ages x and $x + n$

$_nm_x$ age-specific mortality rate for age group x to $x + n$

e_x expectation of life at exact age x

Figure 1. Typical shapes of the $1(x)$ and ${}_1q_x$ functions of a life table





Consider ages 20 and 25. In the life table displayed in table 1, 1(20)—the number of survivors to age 20—is 84,703, and 1(25)—the number of survivors to age 25—is 83,052. Hence, the number of persons dying between ages 20 and 25 equals the difference between those numbers, that is, 84,703 − 83,052 = 1,651. Note that the number 1,651 appears in the line corresponding to age 20 under the column headed $_nd_x$, a notation that stands for the number of deaths occurring between ages x and $x + n$. Thus, $_5d_{20} = 1{,}651$. All the other numbers in column 4 of table 1 are calculated in the same way.

Once the number of deaths occurring in the hypothetical birth cohort in each age interval is known, the probability of dying in each age interval can be calculated. For instance, if 1,651 deaths occur among the 84,703 survivors to age 20 during the next five years of their lives, the probability of each dying before reaching age 25 is 1,651/84,703 = .0195. The number .0195 appears in the line for age 20 of the life table under the column headed $_nq_x$, which is the actuarial notation for the probability of dying between ages x and $x + n$.

The lower panel of figure 1 illustrates the typical shape of the probability of dying at each age, $_1q_x$. Note that the probability of dying is generally high among children under age 5, and especially among children under age 1 (i.e. infants). It falls to a minimum around age 10 and rises gradually up to age 50 or so. Thereafter it rises steeply until very high levels are reached in old age.

Although this *Guide* is concerned mainly with the estimation of probabilities of dying between birth and certain ages in childhood, $_nq_0$, it is worth defining here the rest of the life-table functions, which are displayed in table 1. Their derivation requires the introduction of a new concept: the time lived by survivors between exact ages.

Consider again the interval between exact ages 20 and 25 and note that $l(20)$ is 84,703 and $l(25)$ is 83,052 (that is, out of 100,000 persons born alive, 84,703 survive to exact age 20 and 83,052 survive to exact age 25). Clearly, each of the 83,052 survivors to age 25 lives five years between exact ages 20 and 25, for a total of 5 × 83,052 = 415,260 years lived. However, the 1,651 persons who die also contribute some years lived to the total. Assuming, for simplicity's sake, that all those who die do so at the midpoint of the interval—that is, at exact age 22.5—each one therefore contributes 2.5 years of life, for an additional 2.5 × 1,651 = 4,128 years lived. Hence, the total number of years lived between exact ages 20 and 25 by the hypothetical cohort under consideration is the sum of those quantities—419,388. This value is denoted by $_5L_{20}$ and, in general, the $_nL_x$ function represents the number of person-years lived by the hypothetical life-table cohort between exact ages x and $x + n$.

The $_nL_x$ function is the basis for the calculation of a valuable summary measure of mortality conditions, the expectation of life at birth. If the $_nL_x$ values are cumulated from birth to the highest age to which anyone survives—say 100—the resulting sum will be the total number of years lived by the hypothetical life-table cohort during its lifetime. The average number of years lived by each member of that cohort will then be that total divided by the initial cohort size (the radix, denoted by $l(0)$. Such an average is known as the expectation of life at birth, e_0, an index that summarizes mortality conditions at all ages. In table 1 the last column shows values of the e_x function, that is, the expectation of life at exact age x. The first value is e_0; the others represent the average number of additional years of life expected by each of the survivors to exact age x.

The $_nL_x$ function also allows the calculation of another important set of mortality measures: age-specific death or mortality rates. Death rates measure the velocity at which deaths occur in a given population through time. Their numerator is the number of deaths observed at a given age or for a given age group during a certain period, and their denominator is the time or duration of exposure to the risk of dying experienced during that period by the population being considered. In the case of a life-table cohort, the time of exposure to the risk of dying is provided by the number of person-years lived between one exact age and another, that is, by the $_nL_x$ function. Hence, the death rate between ages x and $x + n$, denoted by $_nm_x$, is defined as

$$_nm_x = \frac{_nd_x}{_nL_x} \tag{1.1}$$

Put another way, $_nm_x$ is the number of deaths of persons aged x to $x + n$ per person-year lived by the hypothetical life-table cohort between those ages. Note that this measure is intrinsically different from $_nq_x$, which represents the number of deaths of persons aged x to $x + n$ per surviving person at age x. In other words, death rates are measures of deaths per unit of time of exposure, whereas probabilities of dying are measures of deaths per person exposed. As columns 5 and 7 of table 1 show, the quantitative difference between the two measures is substantial, largely because $_nm_x$ is a rate per person-year while $_nq_x$ is generally a probability over a period of five years.

Measurement of mortality in childhood

The estimation of mortality in childhood has traditionally focused on mortality below age 1 because, as shown in figure 1, mortality at early ages is highest among infants (persons under age 1) and because measures of mortality for the age range 0 to 1 can be obtained solely from registration data when those data are reliable.

However, given the lack of reliable registration data in most developing countries and the widespread use of indirect methods to estimate mortality in childhood, attention has slowly shifted to the measurement of mortality over an expanded range in childhood. Thus, UNICEF has recently been publishing sets of estimates of mortality in childhood that include not only infant mortality, $_1q_0$, but also under-five mortality, $_5q_0$, for all the countries of the world (see, for instance, UNICEF, 1986, 1987a, 1987b, 1988a, and 1988b). Such a shift has come about mainly for two reasons: first, the realization that in many countries mortality levels among children older than 1 can be substantial, and, second, the fact that the most widely used indirect method of estimating mortality in childhood, the Brass method, produces more reliable estimates of under-five mortality than of infant mortality.

Note that the indices used by UNICEF are probabilities of dying between certain ages: infant mortality is the probability of dying between birth and exact age 1, ${}_1q_0$; child mortality is the probability of dying between exact ages 1 and 5, ${}_4q_1$; and under-five mortality is the probability of dying between birth and exact age 5, ${}_5q_0$. Throughout this *Guide* probabilities are used as indicators of mortality in childhood. To simplify notation, probabilities of dying between birth and exact age x, instead of being denoted by the standard notation, ${}_xq_0$, are denoted by $q(x)$. Note, however, that in referring to the probability of dying between exact ages 1 and 5, also known as child mortality, the traditional notation ${}_4q_1$ will be used, since the age span in this case does not start at birth.

To give the reader an idea of the values that infant and under-five mortality estimates may take, table 2 shows average estimates and projections of mortality in childhood for the major regions of the world during the periods 1950-1955, 1965-1970 and 1980-1985. Note that the more developed regions exhibit consistently lower infant and under-five mortality than do developing regions. Africa, in particular, is characterized by very high mortality in childhood. Recent estimates prepared by the United Nations Population Division (United Nations, 1988) show that infant mortality, $q(1)$, currently varies from a low of 6 deaths per 1,000 live births to a high of over 150 deaths per 1,000. Under-five mortality, $q(5)$, varies between 7 and over 250 deaths per 1,000 live births. Hence, in countries with the highest mortality, slightly more than one out of every six children dies before the age of 1 and one out of every four dies before reaching age 5.

COHORT VERSUS PERIOD MEASURES OF MORTALITY IN CHILDHOOD

It was stated earlier that, in constructing life tables, demographers often use hypothetical cohorts because of the practical constraints inherent in following a real birth cohort through its entire life. However, when the age span of interest corresponds to childhood only or, more specifically, is the age range 0 to 5, the drawbacks of dealing with real cohorts are less serious. Consequently, measures of mortality in childhood referring to real cohorts, called cohort measures, are relatively common in the literature. In order to interpret such measures correctly, the reader should be aware of how cohort measures differ from period measures, which refer to hypothetical cohorts that reflect the mortality conditions prevalent during a given period (a year in most instances).

Consider the problem of counting the deaths occurring before age 1 to the cohort born in 1979. Since the dates of birth of the members of that cohort are likely to span the whole range of dates between 1 January 1979 and 31 December 1979, in order to count all deaths before age 1, it is necessary to observe the cohort from 1 January 1979, when its first members are born, to 31 December 1980, when its last members become 1. In other words, a two-year observation period is necessary to estimate the incidence of mortality among cohort members aging, on average, one year.

Now suppose that, rather than being interested in the deaths occurring in a particular birth cohort, one wants to know how mortality affects persons under age 1 in a particular year, say 1980. Note that persons under 1 in 1980 include not only those born between 1 January and 31 December 1980, who will clearly be under age 1 during the whole year, but also those born in 1979 who will be under age 1 during at least part of 1980. Thus, to measure mortality among persons under age 1 in 1980, information is needed on deaths occurring in 1980 among members of two birth cohorts: that born in 1979 and that born in 1980.

The Lexis diagram (figure 2) provides a graphic illustration of the relation between cohort and period measures. The horizontal axis of the diagram represents time in calendar years, while the vertical axis represents age. Then, the diagonal lines in the diagram represent the trajectory of persons as they age. Thus, the line AE

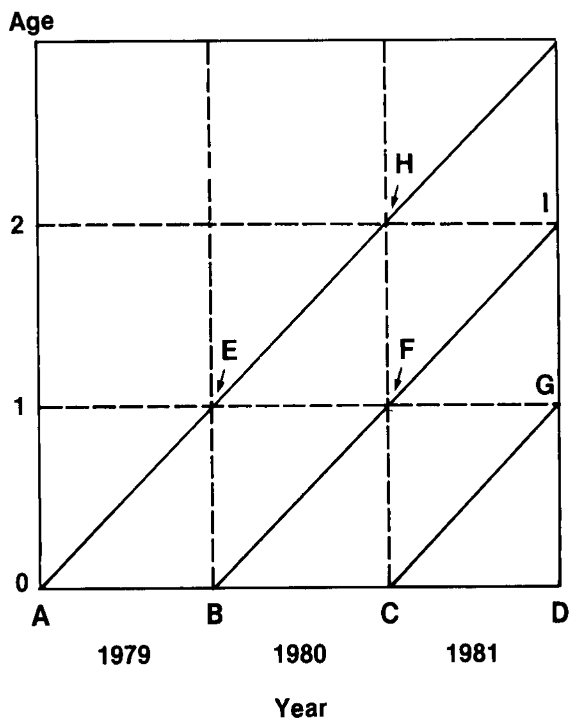
TABLE 2. ESTIMATES OF THE PROBABILITIES OF DYING BY AGES 1 AND 5, $q(1)$ AND $q(5)$, BY MAJOR REGION, 1950-1955, 1965-1970 AND 1980-1985

	Probability of dying by age 1 (per 1,000 births)			*Probability of dying by age 5 (per 1,000 births)*		
Major region	*1950-1955*	*1965-1970*	*1980-1985*	*1950-1955*	*1965-1970*	*1980-1985*
World	156	103	78	240	161	118
More developed regions	56	26	16	73	32	19
Less developed regions	180	117	88	281	184	134
Africa	191	158	112	322	261	182
Latin America	125	91	62	189	131	88
Northern America	29	22	11	34	26	13
East Asia	182	76	36	248	106	50
South Asia	180	135	103	305	219	157
Europe	62	30	15	77	35	17
Oceania	67	48	31	96	67	40
Union of Soviet Socialist Republics	73	26	25	102	36	31

Source: *Mortality of Children under age 5: World Estimates and Projections, 1950-2025*, Population Studies, No.105 (United Nations publication, Sales No. E.88.XIII.4).

represents persons born on 1 January 1979 who reach age 1 on 1 January 1980, while line BF represents persons born on 31 December 1979 who reach age 1 on 31 December 1980. That is, the parallelogram AEFB represents the cohort born in 1979 as it ages from 0 to 1. Since squares of the type BEFC represent yearly periods, it can be seen that, as the 1979 cohort ages, it spans parts of the 1979 and 1980 periods. Conversely, in the 1980 period (BEFC), parts of two cohorts find themselves in the age range 0 to 1: the one born in 1979 and represented by the triangle BEF and that born in 1980, whose triangle is BFC. Thus, the deaths of children under age 1 in 1980 comprise deaths of some children born in 1979 and of some born in 1980.

Figure 2. Relation between cohort and period measures shown by a Lexis diagram



This example illustrates how period measures represent the combined experience of different birth cohorts, whereas cohort measures represent the combined experience of cohort measures during different periods. The Lexis diagram illustrates this by showing how the cohort diagonals cut across periods while the vertical bars representing periods cut across different cohorts.

In this *Guide,* the aim is to obtain period measures of mortality in all instances. However, to understand how those measures are derived, it is often necessary to consider the interplay between cohort and period indices.

Model life tables

In many countries where death registration is incomplete or non-existent, adequate life tables cannot be constructed from the available data. Indeed, little may be known about the actual age pattern of mortality of their populations. Model life tables, which represent expected age patterns of mortality, have been developed for use in such cases.

A number of model-life-table systems exist, but in this *Guide* only two will be used, the Coale-Demeny regional model life tables (Coale and Demeny, 1983) and the United Nations model life tables for developing countries (United Nations, 1982).

The Coale-Demeny life tables consist of four sets or models, each representing a distinct mortality pattern. Each model is arranged in terms of 25 mortality levels, associated with different expectations of life at birth for females in such a way that e_0 of 20 years corresponds to level 1 and e_0 of 80 years corresponds to level 25. The four underlying mortality patterns of the Coale-Demeny models are called "North", "South", "East" and "West". They were identified through statistical and graphical analysis of a large number of life tables of acceptable quality, mainly for European countries.

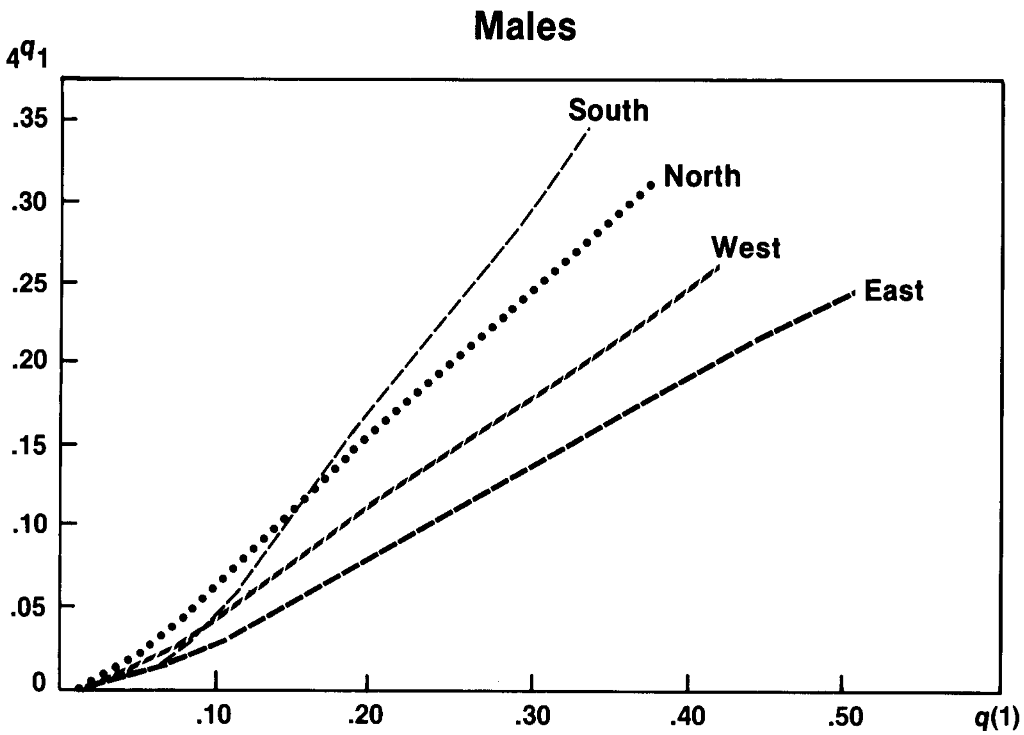
The United Nations models encompass five distinct mortality patterns, known as "Latin American", "Chilean", "South Asian", "Far Eastern" and "General". Life tables representative of each pattern are arranged by expectations of life at birth ranging from 35 to 75 years. The different patterns were identified through statistical and graphical analysis of a number of evaluated and adjusted life tables for developing countries.

Model life tables play a crucial role in the estimation of mortality in childhood. They underlie the derivation of the estimation methods themselves and serve in evaluating the results obtained. Thus, to make proper use of model life tables in estimating child mortality, it is necessary to be familiar with the characteristic patterns that they embody, especially at younger ages. Figures 3 and 4 show one way of comparing those patterns. In both graphs the values of infant mortality, $q(1)$ (the probability of dying by exact age 1), have been plotted against the values of child mortality, ${}_4q_1$ (the probability of dying between exact ages 1 and 5), for each model. Thus, each curve in figures 3 and 4 represents the typical relationship between infant and child mortality in a given life table model.

With respect to the Coale-Demeny models for both males and females, figure 3 shows that for any given value of $q(1)$ above .15, model East produces the lowest mortality between ages 1 and 5, ${}_4q_1$, followed by West and then North. Model South's pattern at young ages overlaps that of East for very low values of $q(1)$, crosses that of West for intermediate values and goes beyond that of North at high values of infant mortality. In other words, model East is appropriate for populations where the risks of dying between ages 1 and 5 are low with respect to those of dying in infancy, whereas model North is appropriate when the former are high with respect to the latter. Model West, falling in between those two, is a good compromise as an "average" model.

Figure 4 shows the equivalent comparisons for the United Nations models. Notice that, in contrast with the Coale-Demeny models, the curves do not intersect and that the order of the models varies by sex. However, the proximity of the curves corresponding to all the patterns

Figure 3. Relationship between infant mortality, $q(1)$, and child mortality, ${}_4q_1$, in the Coale-Demeny mortality models



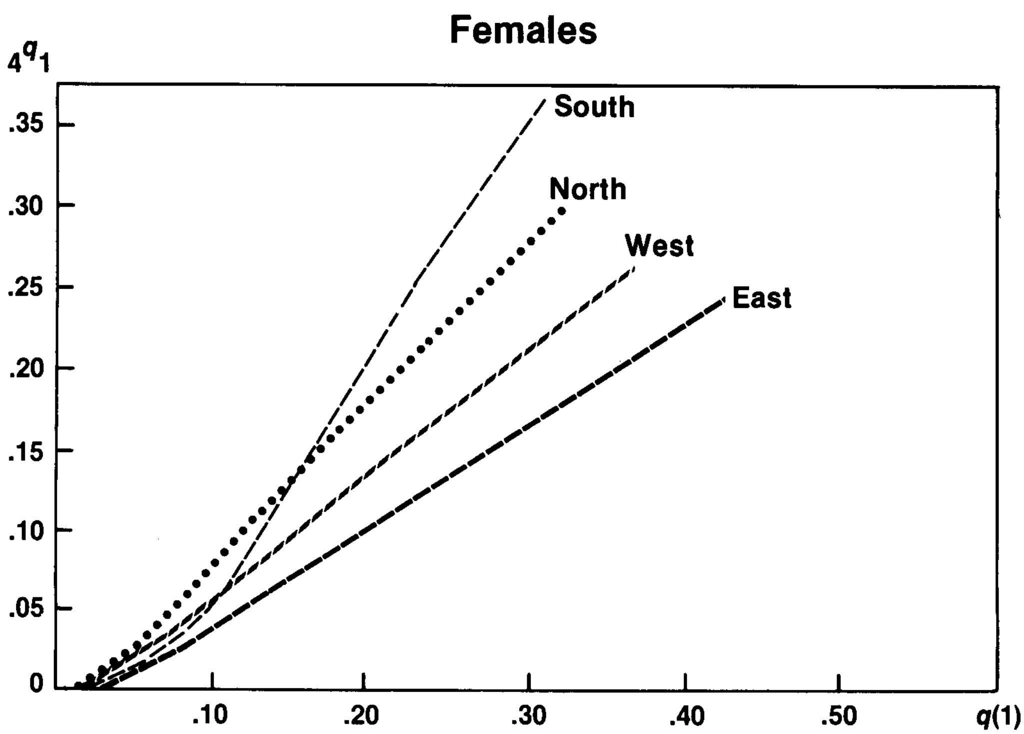
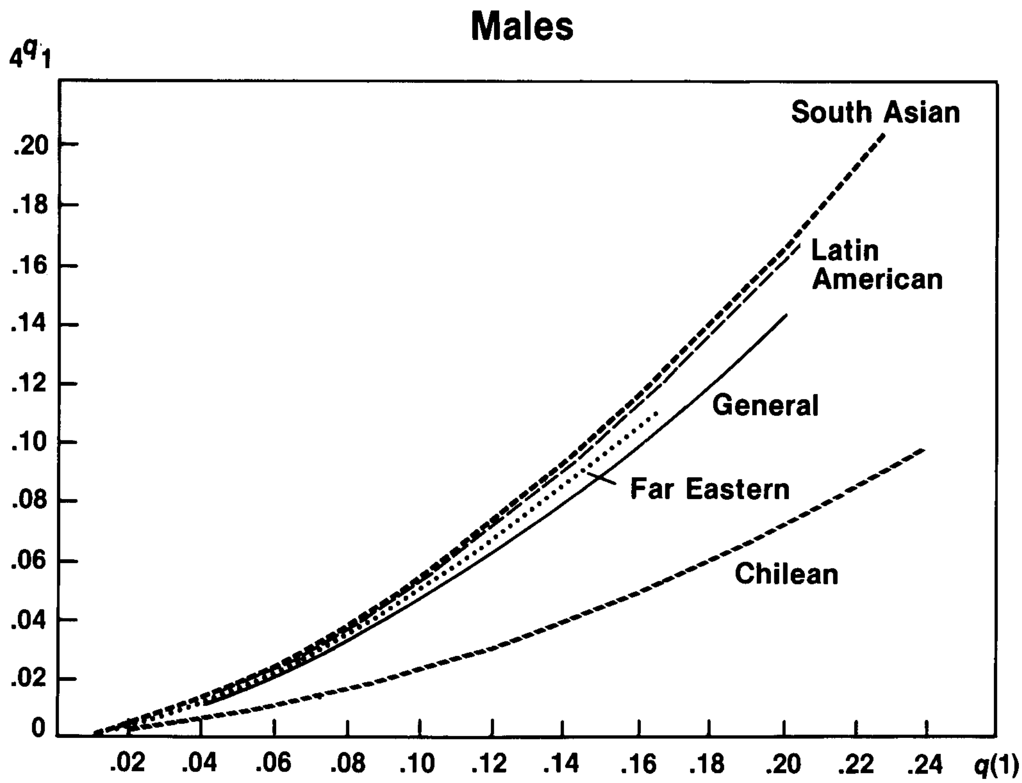
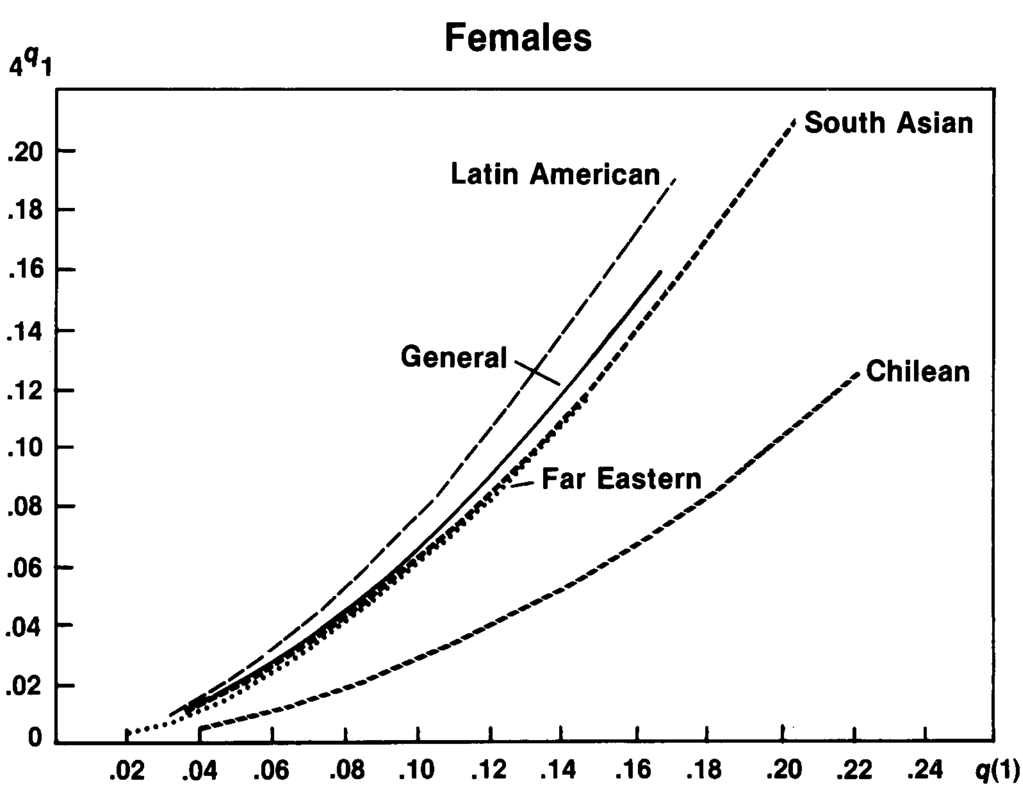


Figure 4. Relationship between infant mortality, $q(1)$, and child mortality, ${}_4q_1$, in the United Nations mortality models





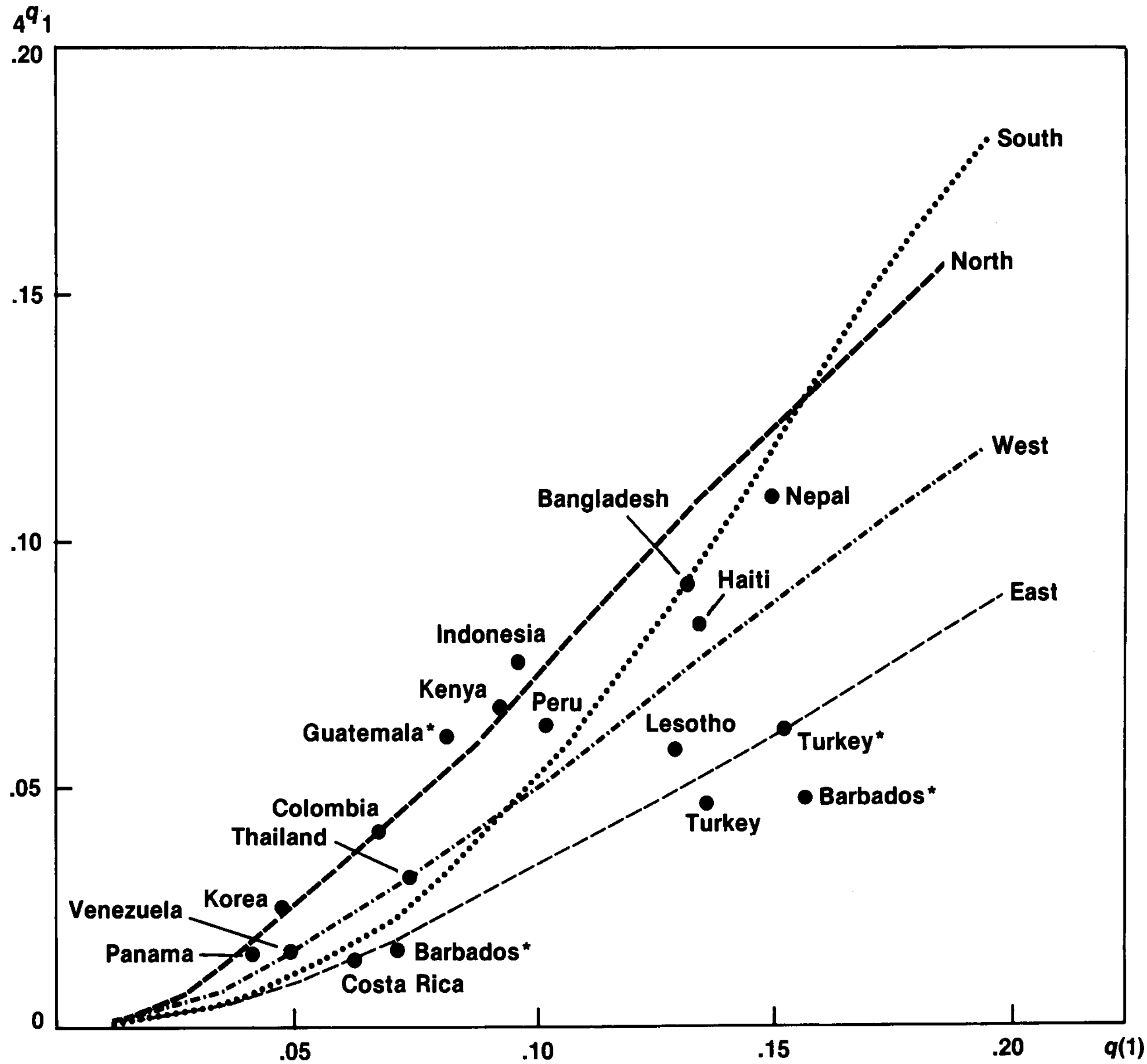
except the Chilean one implies that the United Nations models are less differentiated at younger ages than the Coale-Demeny models. The marked differences existing between the Chilean pattern and all the others should be noted, especially since the Chilean pattern is "more East than East", in that it represents the experience of a population whose mortality risks between ages 1 and 5 are very low compared with those below age 1.

The importance of these models and their distinctive traits will become evident during the description and use of the methods presented below. Those interested in obtaining a more detailed description of model life tables in general may consult chapter I of *Manual X: Indirect Techniques for Demographic Estimation* (United Nations, 1983b), chapters 1 and 2 of *Regional Model Life Tables and Stable Populations* (Coale and Demeny, 1983) and chapters I to IV of *Model Life Tables for Developing Countries* (United Nations, 1982).

Observed patterns of mortality in childhood and the model life tables

To give the reader a sense of how well the mortality models available reflect the actual experience of different populations, figures 5 and 6 compare the relationship

Figure 5. Comparison of country-specific estimates of infant and child mortality with the Coale-Demeny mortality models



Sources: For most countries, the estimates shown are those referring to the period 0-9 years before the World Fertility Survey and published in Shea O. Rutstein, *Infant and Child Mortality: Levels, Trends and Demographic Differentials*, Comparative Studies, No. 24 (London, World Fertility Survey, 1983); the upper right estimate for Turkey was obtained from a multiround survey (1966-1967 Turkish Demographic Survey); the estimates for Barbados were calculated from vital registration data referring to 1945-1947 (upper right) and 1959-1961 (lower left); for Guatemala the estimates used refer to 1975-1980 (see *Mortality of Children under Age 5: World Estimates and Projections, 1950-2025*, Population Studies, No. 105 (United Nations publication, Sales No. E.88.XIII.4). For the mortality models (North, South, East, West), see Ansley J. Coale and Paul Demeny, *Regional Model Life Tables and Stable Populations* (Princeton, Princeton University Press, 1966).

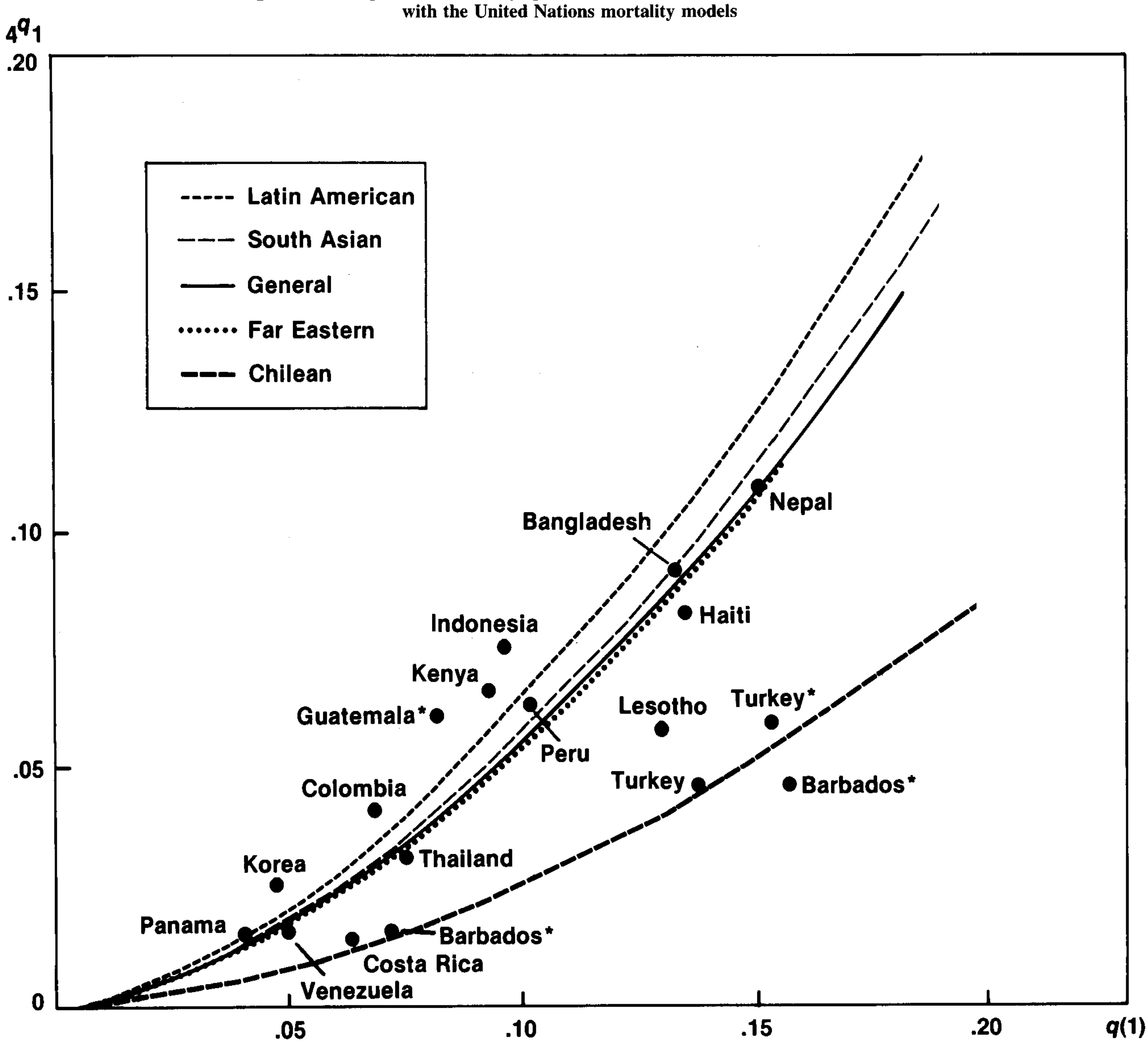
*Estimates obtained from sources other than the World Fertility Survey.

between the infant and child mortality typical of the different model life tables with that observed in selected countries. The data for most of the countries depicted were derived from the set of World Fertility Surveys carried out during the second half of the 1970s. The estimates for Barbados and Guatemala and one of the estimates for Turkey were obtained from other sources.

For the most part, the estimates of $q(1)$ and ${}_4q_1$ plotted in figures 5 and 6 were derived from the fertility histories of women interviewed. A fertility history is the series of dates of birth and, if appropriate, dates of death of all the children a woman has had. The estimates of $q(1)$ and ${}_4q_1$ used here were obtained from the births and deaths of children under age 5 occurring during the 10 years preceding each survey.

Bearing in mind that the accuracy and reliability of the country estimates displayed in figures 5 and 6 may vary, it is useful to consider the degree to which they can be approximated by existing mortality models. Figure 5 shows that the Coale-Demeny models provide excellent approximations for a few countries: Colombia is North, Thailand and Venezuela are West, Bangladesh is South, and Costa Rica and the upper point for Turkey are East. For a few other countries, the models provide very good

Figure 6. Comparison of country-specific estimates of infant and child mortality with the United Nations mortality models



Sources: For most countries, the estimates shown are those referring to the period 0-9 years before the World Fertility Survey and published in Shea O. Rutstein, *Infant and Child Mortality: Levels, Trends and Demographic Differentials*, Comparative Studies, No. 24 (London, World Fertility Survey, 1983); the upper right estimate for Turkey was obtained from a multiround survey (1966-1967 Turkish Demographic Survey); the estimates for Barbados were calculated from vital registration data referring to 1945-1947 (upper right) and 1959-1961 (lower left); for Guatemala the estimates used refer to 1975-1980 (see *Mortality of Children under Age 5: World Estimates and Projections, 1950-2025*, Population Studies, No. 105 (United Nations publication, Sales No. E.88.XIII.4). For the mortality models (Latin American, Chilean, South Asian, Far Eastern and General), see *Model Life Tables for Developing Countries*, Population Studies, No. 77 (United Nations publication, Sales No. E.81.XIII.7).

*Estimates obtained from sources other than the World Fertility Survey.

approximations: Korea, Panama and Kenya are close to North, and the lower point for Barbados is close to East. There are other countries, however, for which the approximation provided by the Coale-Demeny models is less satisfactory, though compromises may be reached if a single model needs to be selected to represent each of them. Thus, for instance, Guatemala and Indonesia may be approximated by model North; Peru and Nepal by South; Haiti by West; and Lesotho, the lower point for Turkey and the upper point for Barbados by East.

Figure 6 shows the same comparison between the United Nations models and country-specific estimates. It is interesting to note that some of the countries that were fit very well by the Coale-Demeny models are no longer close to any United Nations model (for instance, Korea, Colombia and Kenya). On the other hand, some countries whose estimates are relatively far from the Coale-Demeny models are close to certain United Nations models (e.g., Nepal fits the General pattern and Turkey is close to the Chilean). Among the rest of the countries considered, the majority can be fit relatively well by either the Coale-Demeny or the United Nations models, though in particular instances one set of models provides a better fit than the other. Thus, while Costa Rica appears to be exactly East and Venezuela and Thailand are clearly West, Panama is Latin American. There remain, however, countries that are not adequately approximated by any of the models used here. Indonesia, Guatemala, Lesotho and the upper point for Barbados are some examples. To a lesser extent, Peru and Haiti also belong to that group, although they are closer to the United Nations models than to the Coale-Demeny models.

These comparisons show that the models generally provide good fits for the data observed on actual populations. However, and perhaps not surprisingly, the real world exhibits greater variety than is captured by available models. Even though some of the differences between the models and country-specific estimates may arise from errors in the basic data, it is certain that different mortality patterns exist. As will be seen, one of the challenges in using the Brass method is to make allowance for the appropriate mortality pattern in each case.