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Projecting Mortality for All Countries

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New procedures for projecting mortality in each country modestly change previous mortality projections.

As part of its worldwide population projections, the Bank annually provides projections of mortality in each country. Bulatao and Bos reviewed and updated those procedures.

Basically, mortality has been projected by first projecting male and female life expectancy according to standard schedules and then choosing life tables (which give the age pattern of mortality) for successive periods to give the desired sequences of life expectancy levels.

Bulatao and Bos present new procedures for projecting short-term (one or two decades) and long-term (one or two centuries) mortality rates. These procedures involve calculating rates of change for and separately projecting male and female life expectancy and infant mortality and then selecting appropriate model life tables.

Bulatao and Bos derived the approaches to projecting life expectancy and infant mortality from analysis of data for developed and developing countries.

For female life expectancy, alternative maxima of 82.5 and 90 years are used in defining logistic functions for increase over time. Male life expectancy is currently 6.7 years lower than female life expectancy in developed countries, and this differential is assumed to apply at the maximum.

In the short term, the rate of change in life expectancy in a particular country can be predicted from its rate of change in the previous five years and from female secondary enrollment. For the longer term, alternative logistic functions are defined to give medium, rapid, and slow improvements in life expectancy.

The infant mortality rate can also be represented by alternative logistic functions that allow the rate to decline to either 6 or 3 per thousand. In the short term, the trend can be predicted from the previous trend. For the long term, Bulatao and Bos define a medium trend and alternative rapid and slow trends.

"Split" life tables can be chosen from the Coale-Demeny models, using the infant mortality rate to determine which level to use for mortality at younger ages, and life expectancy to determine which level to use for older ages.

Changes from previous mortality projections resulting from these new procedures are mostly modest. Projected life expectancies generally stay within a few percentage points of older projections. Infant mortality and crude death rates vary somewhat more. Projected population is affected only slightly; a 2 percent change is close to the maximum effect.

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CONTENTS

This exercise is an attempt to develop a method for projecting mortality trends in all countries into the future, both over the short term (for one or two decades) and over the long term (for one or two centuries). On the critical assumption that the future will resemble what we know of the recent past, we seek a heuristic model for mortality projections that is universally applicable. Detailed country by country and disease by disease examination might yield better predictions of future mortality, but is quite cumbersome if one wishes to project all countries of the world. Ultimately, of course, future trends in mortality, especially over longer periods, are largely unknowable. Thus this exercise does not attempt to predict mortality so much as to project it into the future given reasonable, though inevitably somewhat arbitrary, assumptions.

Two indicators are the focus of this exercise: life expectancy at birth and the infant mortality rate. The projection of the age pattern of mortality will be considered but no empirical analysis performed. In this introduction, the reasons for focusing on life expectancy and infant mortality will be discussed and a preview of the major issues will be provided. Then previous projection approaches will be briefly summarized. The current exercise is meant to update procedures for projecting mortality for the World Bank, which are among those to be reviewed. Then analysis will be presented separately for life expectancy and infant mortality, covering appropriate representations of universal time trends and country-specific trends and how they might be predicted. Finally, illustrative projections will be used to show the effects of the derived procedures, and some conclusions will be drawn.

Life expectancy at birth and the infant mortality rate together provide a much better description of mortality than the crude death rate, and sufficient time-series data exist on these two variables for the detection of trends. More precise pictures of mortality could be obtained with age and cause-specific rates leading to complete life tables, but data on these are more sparse and generalizations correspondingly much more difficult. Instead, work on sequences of model life tables (Coale and Demeny 1983; Coale and Guo 1989) can be relied on once these key mortality parameters have been projected.

Current projections of mortality for multiple countries involve one of two procedures: incrementing life expectancy according to some schedule and applying appropriate life tables, or selecting some optimal life table toward which mortality rates gradually converge. The procedure considered here is of the first type. Essentially we attempt to refine previous schedules of increments to life expectancy, adjusting them to more closely reflect recent experience, and to take infant mortality into account in selecting life tables.

Here is a brief preview of critical issues considered below.

- What data on mortality should be used to represent recent trends? "Good" data on life expectancy based on empirically derived life tables will be considered, but will be shown to give a rather different picture from weaker data. Some amalgam will be necessary.

- Is any mathematical representation of mortality change appropriate? No perfect model exists, but logistic models will be applied for life expectancy and infant mortality.

- Should life expectancy be allowed to increase indefinitely, or should it be asymptotic to some limit? We will assume limits and, lacking precognition, impose two alternative sets of limits, the first set (the "limited" set) assuming that life expectancy will not progress far beyond current maximum levels and the second set (the "extended" set) assuming that substantial improvement will still be made.

- Can current socioeconomic indicators predict future mortality? They will be shown to have relatively little power to predict rates of improvement. Recent mortality trends, on the other hand, do predict future trends over a decade or so.

- Will separate projections of life expectancy and infant mortality be consistent? We will find reasonable consistency, but also some need rules to prevent too great divergence.

- Will reliance on recent trends radically alter expected mortality in World Bank projections? Some differences will appear, but they are mostly modest.

PREVIOUS WORK

We consider, first, the methods in use for projecting national mortality levels in numerous countries simultaneously; and second, calculations of and speculations about ultimate limits to life expectancy.

Projection methods. Although a variety of methods exist for projecting age-specific mortality (e.g., Pollard 1987), current projections of multiple countries generally rely on only one or two methods and show many similarities. The United Nations Population Division and the World Bank both rely on model life tables. Projecting population in Latin American countries only, the Centro Latinoamericano de Demografia (CELADE) relies on an optimal or ultimate life table toward which all countries converge. The U.S. Census Bureau relies on model life tables and, in some cases, on an optimal life table. We consider these procedures briefly here (but do not deal with the evolution of U.N. procedures, nor with other approaches taken in the past, which are covered in Frejka 1981).

The U.N. Population Division extrapolates life expectancy and applies model life tables based on this parameter (U.N. 1989:13-19). Life expectancy is extrapolated separately for males and females, raising it a specific number of years that gradually declines as life expectancy rises. For example, if a country has had "typical" experience with mortality improvement, and if initial male or female life expectancy is under 60 years, the U.N. expects it to rise 2.5 years in the next quinquennium. For another typical country, if initial life expectancy is between 75 and 77.5, the U.N. expects the increment for males to be .5 years per quinquennium, and for females to be 1.0 years per quinquennium. Intermediate increments are defined for intermediate levels of life expectancy. If a country has had unusually fast or unusually slow mortality improvement, schedules of increments that are slightly higher or slightly lower are applied instead. No definition is given of what constitutes slow, typical, and fast mortality improvement for purposes of choosing a schedule of increments. (Presumably comparisons of previous life expectancy gains with the three schedules of increments can be used.) These increments were obtained by taking means of quinquennial increments by initial life expectancy levels across low- and moderate-mortality countries for quinquennia from 1955 to 1985.

Based on the resulting life expectancy estimates, the U.N. chooses appropriate life tables from among nine models: the four Coale-Demeny (1983) families (North, South, East, and West) and the five U.N. (1982) models (General, Latin American, Chilean, Far Eastern, and South Asian). These model families are extended to give, at a maximum, a male life expectancy of 82.5 years and a female life expectancy of 87.5 years. Model life tables with these maximum life expectancies were devised by adjusting downward the q_x values in life tables which combined data on a few low-mortality countries. Each family of model life tables was then required to converge to these ultimate life tables.

The World Bank procedures are roughly parallel (Zachariah and Vu 1988:xiv-xvi; Vu, Bos, and Bulatao 1988:2-6). Female life expectancy is incremented according to schedules similar to those used by the U.N., with larger increments at lower levels of life expectancy. Two schedules are provided, one for countries with female primary enrolment under 70 percent and the other for all other countries. These schedules were obtained from separate regressions for these two groups of countries on initial life expectancy in 1965-69 of life expectancy increments in the following decade. The incremented life expectancies are used to select appropriate levels of the Coale-Demeny life tables. Male life tables are chosen at the same level as the female tables, or with life expectancy incremented according to similar schedules. At lower life expectancy levels, South or North family tables are used; at higher levels, West family tables are used. In the long run, females are allowed to reach a life expectancy of 82.5, and males are limited to a life expectancy of 76.6.

The U.S. Census Bureau (as an account they provided indicates) first estimates logistic functions by country and sex, using in each case two historical estimates of life expectancy, or a current estimate and a judgment of probable life expectancy in 2000, or (for developed countries) a current estimate and life expectancies of 80 for males or 86 for females by 2050. These functions are assumed to have lower bounds of 25 and upper bounds of 79-81 for males and 86-87 for females. The annual increment given by these functions is required to be within the range provided by the U.N. projections. Age patterns for mortality are then obtained in one of three ways: directly from Coale-Demeny model life tables; by applying to an empirical life table (where one is available) the relative changes in mortality rates between levels of Coale-Demeny model life tables; or by generating interpolated life tables between an empirical life table and an optimal life table for all countries based on Japanese and Swedish data. Projections of U.S. mortality are done separately, and involve more complex operations (Long and McMillen 1987:154-155).

The similarities are more notable than the contrasts among these procedures. The annual increments to life expectancy used by the U.N. and the World Bank are quite similar, as will be illustrated below, and the Census Bureau requires that its procedures produce increments in the same range. In addition, the World Bank increments can be approximated with a logistic curve (Bulatao and Elwan 1985:2-4), the type of curve applied by the Census Bureau. Similar logistic curves to represent rapid mortality decline have also been defined (Bulatao and Elwan 1985:10-14).

The CELADE procedure in principle is not that different from any of these. Survivorship ratios are initially given by life tables selected for each country, and the logits of these ratios converge linearly to those of optimal life tables for all countries (Pollard 1987:65). The U.N., World Bank, and Census Bureau procedures all to some degree also involve such optimal life tables. However, whether the specific changes in mortality parameters like life expectancy in the CELADE projections match those in the other sets of projections is not known.

Limits to life expectancy. These projection methods all make assumptions about the maximum attainable life expectancy, at least within the projection periods considered. Between its last two assessments of population prospects, for instance, the U.N. (1986a, 1989) raised assumed maximum levels of life expectancy between the present and 2025 from 75 to 82.5 years for males and from 82.5 to 87.5 years for females. Particularly for longer mortality projections of 50 years or more, maximum levels of life expectancy have significant effect, and we therefore consider what these maxima are.

Two main approaches have been used to estimate maximum levels; neither between nor within approaches has there been agreement. One approach has been to extrapolate observed improvements in mortality and determine some point at which these improvements cease. Extrapolating rates of increase in life expectancy at different ages until the levels converged, Fries (1980) obtained limits for the U.S. of 82.4 years for males and 85.6 years for females, and also determined that these levels would be reached in 2009 and 2018 respectively. Extrapolating life expectancies at birth along exponential curves, which they argued fit the data for advanced developed countries well, Coale and Guo (1989) obtained limits of 76.1-77.8 for males and 83.25-84.9 for females. In these two cases and with other extrapolation exercises, the statistical techniques used affect the results. Even more important, however, are the data used, which represent past conditions and cannot reflect future breakthroughs in mortality reduction.

The other approach has been to determine the effect on mortality of eliminating, deferring, or reducing the impact of particular causes of death. This approach has a long history, dating at least to an 1806 study on the effects of smallpox vaccination (see Bourgeois-Pichat 1978, Pressat 1974). Among more recent work, Bourgeois-Pichat, with Norwegian data, attempted in 1952 to determine the effect of eliminating "exogenous" causes of death, obtaining maximum life expectancies of 76.3 for males and 78.2 for females. In 1978, he revised the limit downward for men to 73.8 and upward for women to 80.3 (barely above current estimates for Norway). Using the Framingham study and focusing on U.S. white adult males, Manton (1986) showed that controlling major risk factors could lead to an increase of 12.3 or 12.8 years (his statistics are ambiguous) in expectation of life at age 30. Even with no changes in mortality rates below 30, this would effectively raise life expectancy at birth for males above 81.

Some of the maximum estimates various authors have made have already been exceeded. Life expectancy in Japan, for instance, is now estimated at 75.6 for males and 81.4 for females (Institute of Population Problems 1989:2). Combining the lowest age-sex specific death rates around the world gives slightly higher life expectancies, 76.2 for males and 82.1 for females (Uemura 1989). In the long run, over 50 years or longer, none of these calculations provide any convincing evidence of specific limits. Thus the question of ultimate limits to life expectancy is unresolvable at this time. We will therefore develop two alternative patterns for projection purposes: the first, the "limited" option, will assume that national life expectancies will not rise greatly beyond current maximum levels; the second, the "extended" option, will assume that they will rise by about ten years.

LIFE EXPECTANCY

First, we discuss the data to be used on expectation of life at birth (e_0). Second, we consider the general trends over time shown in these data. Third, we attempt to determine whether trends for individual countries can be predicted. Fourth, we suggest an approach to projecting life expectancy based on the analysis.

Data. Data on life expectancy by sex (referred to here as data set A) were drawn from United Nations Secretariat (1988a:61-64), which provides the estimates from various collections of life tables, including the input life tables used by Coale and Demeny (1983), a previous U.N. publication (1952), a U.N. (1986b) database for developing countries, and WHO life tables based on registered deaths in developed countries. Many of these life tables were constructed with data for several years. The life expectancy estimates were assumed to pertain to the midpoint of these periods. We needed estimates for at least three years for each country, which reduced the countries considered to 37, with England and Wales, Scotland, and Northern Ireland, as well as Puerto Rico, considered separately.

The only developing countries in the list, aside from Puerto Rico, were Argentina, Hong Kong, Sri Lanka, Martinique, Reunion, and Singapore. For some analyses, even these atypical countries had insufficient data. Therefore, some parallel analysis was run just on developing countries using additional, if less reliable, data. The life-table based estimates were augmented with estimates from the U.N. Demographic Yearbook (various years), from which we excluded, as much as possible, estimates the U.N. obtained by projection. A set of 33 developing countries (set B) was obtained by this process.

General trends. We attempted first to linearize trends over time in these data. Following previous work, we used a logistic transformation, which captures the slower improvement in life expectancy at high levels and at very low levels. (Alternative transformations like exponentials did not fit as well.) The trans' ;nation of life expectancy at time t (e_t) was of the form

$$\text{logit}(e_t) = \log_e [(k_0 + k - e_t) / (e_t - k_0)]$$

where k_0 is a lower limit for life expectancy and (k_0 + k) an upper limit. After some experimentation, k_0 was fixed at 20.

Alternative values of (k_0 + k) were tried: for wom^n, these were 82.5 and 90. Logits using these alternative maxima will be referred to as the "limited" and "extended" transformations. The first value is one level above the highest model life table in the Coale-Demeny set, but is covered in later work by Coale and Guo (1989), which also revises the tables at the highest levels of life expectancy. The second value allows life expectancy to rise much higher in the long term. These two maxima are close to the high and low values for long-run female life expectancy--81.5 and 90.1--projected by the U.S. Social Security Administration (Wade 1988:13).

For men, maximum life expectancy was set at 6.7 years less than women, the current average gap for developed countries. Both a limited and an extended transformation for men were thus defined. The gap between men and women has grown over time, but apparently is no longer growing in some developed countries and may even be narrowing (U.N. Secretariat 1988b). From experience in higher social classes in developed countries, particularly regarding smoking behavior, some argue that the gap could eventually decline (Nathanson and Lopez 1987). However, the generalizability of such trends cannot be assumed, and no firm basis exists so far for assuming either a larger or a smaller sex differential worldwide in the future. Assuming the differential will stay at current developed-country levels, the resulting limits for men--75.8 and 83.3--will again resemble low and high values projected by the U.S. Social Security Administration--75.2 and 83.6 for long-run male life expectancy (Wade 1988:13).

Some indication that the logit transformation serves to linearize trends in life expectancy is given in Table 1, which reports correlations between life expectancy at the beginning of a quinquennium and the rate of change in life expectancy or its logit in that period. Across the set A countries, this correlation is generally negative if life expectancy has not been transformed, indicating more rapid rise in life expectancy from lower levels. By contrast, rates of change in the logit tend to be correlated about as often positively as negatively with initial level across these countries. However, regardless of transformation, an unusual time trend does emerge, with countries in set A at lower levels of life expectancy gaining more around 1960 than countries at higher levels of life expectancy, but the situation being reversed around 1980. The set B data are more difficult to interpret, the data referring to periods that are less consistent across countries. For instance, a 1970-80 rate for one country may be included, in calculating a correlation, with a 1976-79 rate for :her country. The logit transformation does consistently reduce the link between initial level and rate of change, but does not eliminate it.

Time trends in the logit of life expectancy were examined country by country, and appeared to be mostly linear, the exceptions being mainly countries with sharp falls in life expectancy at particular periods. Linear regression was then used to fit a line through the logits for male and female life expectancy in each country. R^2 for these regressions was uniformly high, half the time being above .95 and three-fourths of the time being above .90. Residuals from the

Table 1. Correlations between initial life expectancy and subsequent rate of change in life expectancy and its logit.

Data set and subsequent period	No. of countries	Males			Females		
		Untransformed	Logit, limited	Logit, extended	Untransformed	Logit, limited	Logit, extended
Set A							
1957-62	19	-0.92	0.88	0.91	-0.93	0.82	0.89
1962-67	29	-0.58	0.42	0.52	-0.74	0.44	0.63
1967-72	29	-0.20	-0.07	0.10	-0.12	-0.25	-0.05
1972-77	29	-0.12	-0.25	-0.01	0.02	-0.47	-0.23
1977-82	29	0.22	-0.54	-0.33	0.23	-0.63	-0.41
Set B							
~1957-62	17	-0.41	0.19	0.34	-0.34	0.15	0.27
~1962-67	17	-0.41	0.28	0.36	-0.45	0.31	0.39
~1967-72	20	-0.39	0.32	0.36	-0.12	-0.17	-0.00
~1972-77	20	-0.55	0.14	0.40	-0.69	0.32	0.58
~1977-82	19	-0.36	-0.15	0.15	-0.32	0.00	0.17

Note: The limited transformations assume maxima of 75.8 for men and 82.5 for women. The extended transformations assume maxima of 83.3 for men and 90 for women. Set A data, mostly for developed countries, are from several sets of life tables. Set B data, all for developing countries, add to the life table data estimates from the U.N. Demographic Yearbook.

equations showed no consistent trend.

Table 2 provides the means and some percentiles of the estimated slopes from these regressions for each of four groups of countries: (1) set A countries, using only data for 1950 or later; (2) only those set A countries with pre-1950 estimates, including both pre-1950 and post-1950 data; (3) set B countries, using 1950 and later data; and (4) only those set B countries with pre-1950 estimates, including both pre-1950 and post-1950 data. The set A data give more gradual rates of change than the (probably less reliable) set B data, and countries with pre-1950 data show more rapid change when such data are included. This seems to imply that change in developing countries, or from lower levels of life expectancy, may be more rapid. Given the consistency of these contrasts, reliance solely on the set A data is inappropriate. All data and all cases are pooled to give the last row of each section of the table. On the basis of these pooled estimates, working estimates of rates of change in life expectancy to represent slow mortality decline, medium mortality decline, and rapid mortality decline are given at the bottom of Table 2.

What these coefficients mean is demonstrated in Table 3, which shows the annual increments to life expectancy predicted by using models incorporating the working estimates. If male life expectancy is now 40, for instance, the medium annual gain (based on the limited transformation) is .45 years, as opposed to .22 years using the slow estimate and .69 years using the rapid estimate. If male life expectancy is 70, on the other hand, the medium annual gain is only .18 years.

Table 2. Means and percentiles across countries of rates of change in logit of life expectancies, and working estimates.

Sex, transformation, and data set	N	Mean	Percentile 90th	75th	50th	25th	10th
Males (limited)							
Set A, 1950-85	37	-0.028	-0.006	-0.014	-0.026	-0.039	-0.049
Set A, pre-1950	22	-0.031	-0.023	-0.026	-0.029	-0.034	-0.045
Set B, 1950-85	32	-0.037	-0.011	-0.028	-0.037	-0.046	-C.068
Set B, pre-1950	9	-0.046	-0.034	-0.040	-0.046	-0.052	-0.057
All data, all years	70	-0.035	-0.014	-0.026	-0.034	-0.045	-0.053
Males (extended)							
Set A, 1950-85	37	-0.016	-0.003	-0.008	-0.014	-0.021	-0.032
Set A, pre-1950	22	-0.023	-0.017	-0.019	-0.020	-0.026	-0.035
Set B, 1950-85	32	-0.027	-0.009	-0.019	-0.028	-0.033	-0.039
Set B, pre-1950	9	-0.038	-0.029	-0.032	-0.040	-0.044	-0.047
All data, all years	70	-0.025	-0.009	-0.018	-0.023	-0.034	-0.040
Females (limited)							
Set A, 1950-85	37	-0.035	-0.017	-0.025	-0.035	-0.045	-0.052
Set A, pre-1950	22	-0.034	-0.025	-0.028	-0.032	-0.038	-0.045
Set B, 1950-85	32	-0.036	-0.013	-0.023	-0.037	-0.049	-0.060
Set B, pre-1950	9	-0.043	-0.033	-0.038	-0.042	-0.047	-0.055
All data, all years	70	-0.036	-0.019	-0.027	-0.036	-0.045	-0.053
Females (extended)							
Set A, 1950-85	37	-0.021	-0.010	-0.015	-0.019	-0.026	-0.033
Set A, pre-1950	22	-0.026	-0.017	-0.021	-0.024	-0.029	-0.036
Set B, 1950-85	32	-0.028	-0.010	-0.019	-0.031	-0.037	-0.043
Set B, pre-1950	9	-0.037	-0.026	-0.031	-0.036	-0.043	-0.047
All data, all years	70	-0.027	-0.012	-0.019	-0.025	-0.036	-0.041
Working estimates			Slow		Medium		Rapid
Males (limited)			-0.017		-0.035		-0.053
Males (extended)			-0.010		-0.025		-0.040
Females (limited)			-0.017		-0.035		-0.053
Females (extended)			-0.010		-0.025		-0.040

Figure 1 compares the estimated annual increments to female life expectancy--from the slow, medium, and rapid models, using the limited and extended transformations--with the increments applied by the U.N. Population Division (1989:16) and those previously used by the World Bank (Zachariah and Vu 1988:xvi). In these comparisons, the previous World Bank increments for the high-female-education case are treated as medium estimates and those for the low-female-education case as low estimates. The increments from the medium model appear to agree reasonably well with the previous World Bank pattern and the U.N. pattern. Although the U.N. increments are slightly higher at around 65, at higher life expectancies they fall between the

Figure 1
Annual increments, in years, to female life expectancy from different models, assuming slow, medium, and rapid improvement

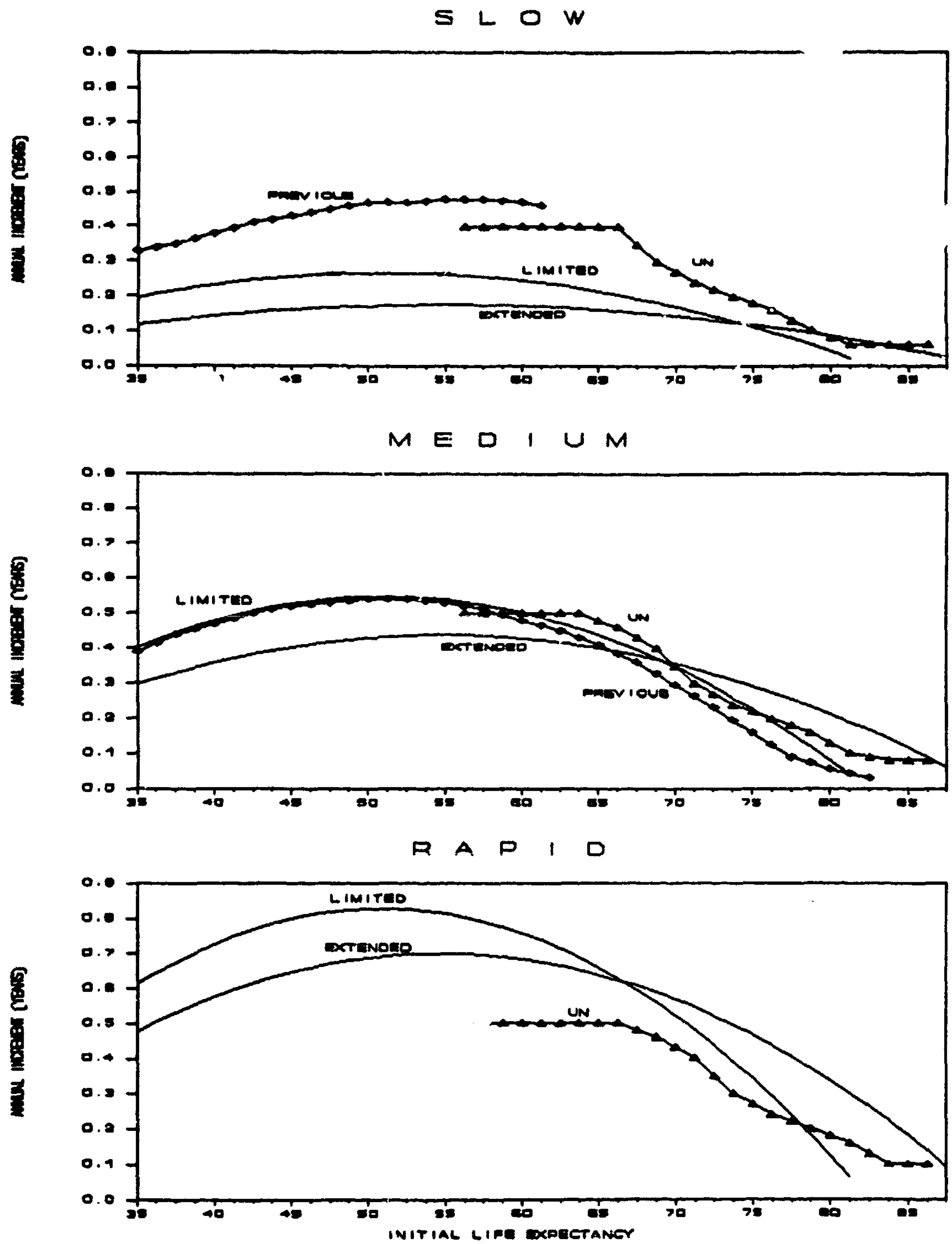


Table 3. Annual increment to life expectancy in years, by sex, with different equations, from varying initial levels.

Sex and initial level	Limited			Extended		
	Slow	Medium	Rapid	Slow	Medium	Rapid
Males						
40	0.22	0.45	0.69	0.14	0.34	0.55
50	0.24	0.48	0.73	0.16	0.39	0.63
60	0.19	0.39	0.59	0.15	0.37	0.59
70	0.09	0.18	0.27	0.10	0.26	0.42
80	--	--	--	0.03	0.08	0.12
Females						
40	0.23	0.48	0.73	0.14	0.36	0.58
50	0.27	0.55	0.83	0.17	0.43	0.69
60	0.24	0.50	0.76	0.17	0.43	0.68
70	0.17	0.35	0.52	0.14	0.36	0.57
80	0.04	0.08	0.12	0.09	0.21	0.34

estimates using the limited and the extended transformations. However, where the slow and rapid models are concerned, the working estimates are slower and more rapid, respectively, than the U.N. patterns, except near the upper limits for life expectancy, where the U.N. continues to allow some improvements. Comparisons of the patterns for males lead to similar conclusions.

Comparisons are also possible with increments to life expectancy estimated by the U.N. from reliable data. For 23 developing countries in the 1950s-60s, the average annual increment was .61 years and varied little by initial life expectancy. For 33 developing countries in the 1960s-70s, the average increments were .62 for countries with initial life expectancies under 50, falling to .24 for countries with initial life expectancies of 65 or higher. For 27 developing countries in the 1970s-80s, the average increments were .76 for countries with initial life expectancies under 50, falling to .37 for countries with initial life expectancies of 65 or higher (U.N. 1988:132). For 24 developed countries, with initial life expectancies anywhere from 65 to 79, annual increments in the late 1970s and early 1980s averaged about .2 (U.N. 1988:140-141). Except at very low levels of life expectancy, these increments resemble the gains provided by the medium working models and fall within the range of the slow and rapid models. At very low levels of life expectancy, these increments are larger than the models provide, possibly because countries with high mortality but good data are a select group.

Predicting specific trends. Trends in life expectancy in specific countries can be predicted from previous trends and from socioeconomic factors. Table 4 shows that, in the set A data, the rate of change in one period is correlated with the rate of change in a previous period. The rate in the immediately preceding quinquennium is the best predictor of the subsequent rate, and as the periods related move farther apart, the correlation declines. From the set B data (Table 5), the same general conclusion cannot be drawn. Only for periods beginning in the early 1980s is the correlation between rates of change in succeeding periods positive; for earlier periods, the correlation is negative, and occasionally large. Inconsistencies in period definition, or less stability

Table 4. Correlations between rate of change in logit of life expectancy and rate of change in preceding periods, set A countries.

Periods correlated	No. of countries	Males (limited)	Males (extended)	Females (limited)	Females (extended)
Previous period and:					
1962-67	19	0.66	0.76	0.57	0.68
1967-72	29	0.60	0.58	0.58	0.57
1972-77	29	0.62	0.57	0.60	0.53
1977-82	29	0.76	0.70	0.73	0.62
Period twice removed and:					
1967-72	19	0.38	0.46	0.30	0.40
1972-77	29	0.19	0.12	0.14	0.13
1977-82	29	0.54	0.40	0.53	0.40
Period thrice removed and:					
1972-77	19	0.14	0.09	0.12	0.16
1977-82	29	0.23	0.04	0.24	0.16
Period four times removed and:					
1977-82	19	0.14	0.10	0.24	0.25

Table 5. Correlations between rate of change in logit of life expectancy and rate of change in previous period, set B countries.

Starting date of subsequent period	No. of countries	Males (limited)	Males (extended)	Females (limited)	Females (extended)
Any year	80	-0.06	-0.14	-0.08	-0.08
Early 1960s	17	-0.68	-0.64	-0.61	-0.59
Late 1960s	14	-0.07	-0.08	0.12	0.08
Early 1970s	20	-0.52	-0.49	-0.09	-0.14
Late 1970s	19	-0.29	-0.34	-0.37	-0.37
Early 1980s	10	0.49	0.48	0.28	0.41

in mortality experience, may be responsible for the unstable pattern with set B data.

Regressions were run to predict rate of change from previous rate of change and various socioeconomic indicators. Given the inconsistencies noted with set B data, only the set A data were used. The socioeconomic variables initially considered were GNP per capita; the female primary and secondary enrolment ratios; female labor force participation; and percent of the population urban. Data were obtained from World Bank files. Initial analysis led to elimination of three of these variables. GNP per capita was not predictive, neither by itself or in association with other variables. The primary enrolment ratio did seem to predict more rapid improvement in life expectancy, but the ratio had limited range, being close to or often above 100 for most of these countries. Female labor force participation did occasionally predict slower improvement in life expectancy, but this was difficult to rationalize. Regressions using the remaining variables are reported in Tables 6 to 8.

Table 6 uses previous rate of change and the female secondary enrolment ratio to predict rate of change in life expectancy; Table 7 uses previous rate of change and percent urban.

Table 6. Regressions for rate of change in logit of life expectancy, with previous rate of change and female enrolment ratio.

Sex, transformation, and period predicted	Previous rate of change		Female secondary enrolment ratio			
	B	(t)	B	(t)	Constant	R^2
Males (limited)						
All periods	0.885	8.28	-0.000318	-2.36	0.01159	0.52
1967-72	0.653	3.79	-0.000028	-0.14	-0.00449	0.36
1972-77	0.736	3.76	-0.000315	-1.31	0.00225	0.43
1977-81	1.150	5.86	-0.000361	-1.15	0.02525	0.59
Males (extended)						
All periods	0.669	6.74	-0.000132	-2.02	0.00277	0.41
1967-72	0.549	3.57	-0.000011	-0.10	-0.00302	0.34
1972-77	0.614	3.26	-0.000122	-0.99	-0.00223	0.35
1977-81	0.895	4.90	-0.000137	-0.97	0.00795	0.50
Females (limited)						
All periods	0.723	6.80	-0.000254	-2.18	0.00379	0.45
1967-72	0.794	3.53	-0.000127	-0.70	0.00159	0.35
1972-77	0.662	3.21	-0.000338	-1.48	0.00039	0.42
1977-81	0.868	5.26	-0.000237	-0.98	0.01241	0.54
Females (extended)						
All periods	0.528	5.27	-0.000092	-1.62	-0.00290	0.30
1967-72	0.627	3.47	-0.000064	-0.63	-0.00112	0.33
1972-77	0.515	2.81	-0.000115	-1.03	-0.00550	0.31
1977-81	0.645	3.98	-0.000070	-0.64	0.00010	0.39

Table 7. Regressions for rate of change in logit of life expectancy, with previous rate of change and percent urban.

Sex, transformation, and period predicted	Previous rate of change		Percent urban		Constant	R^2
	B	(t)	B	(t)		
Males (limited)						
All periods	0.958	9.49	-0.000339	-2.89	0.01331	0.53
1967-72	0.677	3.73	-0.000061	-0.37	-0.00193	0.37
1972-77	0.828	4.62	-0.000364	-1.98	0.00557	0.47
1977-81	1.132	5.88	-0.000407	-1.60	0.02397	0.61
Males (extended)						
All periods	0.735	7.67	-0.000144	-2.46	0.00375	0.42
1967-72	0.553	3.35	-0.000007	-0.07	-0.00320	0.34
1972-77	0.704	4.00	-0.000166	-1.72	0.00094	0.39
1977-81	0.884	5.01	-0.000189	-1.67	0.00987	0.53
Females (limited)						
All periods	0.802	8.02	-0.000192	-1.89	0.00106	0.44
1967-72	0.867	3.66	-0.000107	-0.71	0.00270	0.35
1972-77	0.769	4.00	-0.000176	-0.99	-0.00914	0.39
1977-81	0.876	5.48	-0.000284	-1.48	0.01347	0.56
Females (extended)						
All periods	0.581	5.87	-0.000058	-1.12	-0.00459	0.29
1967-72	0.661	3.28	-0.000031	-0.35	-0.00242	0.33
1972-77	0.570	3.23	-0.000043	-0.48	-0.01005	0.29
1977-81	0.668	4.23	-0.000113	-1.29	0.00281	0.42

If all three predictors were combined, the effects of the two socioeconomic variables would not be significant. In these separate regressions, the two socioeconomic variables have reasonably consistent effects that are sometimes but not always significant. Previous rate of change, on the other hand, always has a strong and significant effect. Regressions using only previous rate of change are shown in Table 8. Using only this predictor, coefficients close to those estimated can be chosen to ensure that predicted rates from successive applications of the equations converge to the medium rates provided above. These form the working equations in Table 8.

Projection approach. One approach to projecting life expectancy that can be devised from these results involves four steps. First, predict rate of change in life expectancy from the equations in Tables 6 and 7. The equations using pooled data across periods are an appropriate choice. The equations using secondary enrolment may be slightly preferable to those using percent urban because the coefficients are slightly more stable across periods, but the other equations could equally be used. Second, to minimize the effect of unusual recent trends, require that the rate of change be within certain limits, such as being no more extreme than the slow mortality decline and rapid mortality decline estimates in Table 1. Third, apply the calculated rate of change for a few years, perhaps 15. The correlations in Table 4 suggest that, after 15 years, rate of change is

Table 8. Regressions for rate of change in logit of life expectancy, with previous rate of change only.

Sex, transformation, and period predicted	B	(t)	Constant	R^2
Males (limited)				
All periods	0.938	8.94	-0.00976	0.48
1967-72	0.652	3.93	-0.00622	0.34
1972-77	0.766	4.12	-0.01983	0.36
1977-81	1.178	6.02	-0.00263	0.56
Males (extended)				
All periods	0.700	7.18	-0.00623	0.37
1967-72	0.549	3.70	-0.00367	0.31
1972-77	0.631	3.57	-0.01083	0.30
1977-81	0.912	5.02	-0.00272	0.46
Females (limited)				
All periods	0.792	7.81	-0.01204	0.41
1967-72	0.804	3.69	-0.00583	0.31
1972-77	0.749	3.92	-0.02151	0.34
1977-81	0.893	5.48	-0.00545	0.51
Females (extended)				
All periods	0.558	5.75	-0.00885	0.27
1967-72	0.627	3.58	-0.00498	0.30
1972-77	0.552	3.25	-0.01320	0.25
1977-81	0.656	4.11	-0.00525	0.36
Working equations				
Limited	0.8		-0.0070	
Extended	0.7		-0.0075	

predicted poorly at best. Alternatively, apply the calculated rate only for one period, and estimate from it the rate for the following period, using the working equations in Table 8, which can be used successively for the next period. Fourth, apply a standard rate of change to life expectancy beyond 15 years, such as the medium mortality decline pattern in Table 1. The entire procedure could be carried out using either the limited or the extended maxima for life expectancy.

The medium decline patterns for males and females are consistent, the rates of change being identical. However, country-specific trends estimated from equations in Tables 6-8 need not be consistent, and could, for a specific country, imply an increasingly large gap between the sexes in life expectancy or even a reversal of the gap. To produce some minimum consistency between male and female trends, limits can be set on the degree to which rates of change diverge.

We reexamined the set A and set B data for the differences in rates of change in male versus female life expectancies. Differences in the rates of change of the logits of less than -.01 and of greater than .02 were rare in the set A data. In the set B data they were more common, these values representing the quartiles of the distribution of differences in rates of change (when the limited transformation was used) or the 16th and 88th percentiles (when the extended transformation was used). For projection purposes, these values can be adopted as limits, adjusting male and female rates of change upward or downward symmetrically when necessary to stay exactly within these limits.

INFANT MORTALITY

Parallel analysis to that on life expectancy was run on infant mortality. The data will be described, general trends will be determined, the prediction of specific country trends will be discussed, and a projection approach will be presented.

Data. Data were drawn from U.N. (1988a) and from World Fertility and Demographic and Health Surveys. Only those developing countries in U.N. (1988a) were included whose estimates (in the judgment of Hill and Pebley [1988], working with the author of the U.N. report) were based on reasonable data rather than informed demographic judgment. Infant mortality estimates greater than 150 per thousand were left out as probably less dependable and largely irrelevant for projection purposes, since most countries are below this level. The resulting data set (set A) included at least two quinquennial estimates between 1960 and 1985 for 91 countries. Estimates will be assumed to apply, for this analysis, to the midpoint of each quinquennium. Again, these data were supplemented with presumably less reliable estimates for 52 other countries (set B) for 1975-80 and 1980-85. The additional data, covering the majority of the developing countries not already included, were drawn from World Bank files, and closely resemble the data in U.N. (1988a) not included in set A.

General trends. The first question was whether some simple transformation could linearize infant mortality trends, which usually show decelerating declines. Roots and logs were tried, but were not satisfactory. Using the cube root does eliminate any correlation between infant mortality level and subsequent rate of change (Table 9), but this transformation fits poorly at low

Table 9. Correlations between infant mortality rate at start of period and rate of change within period in infant mortality, its roots, log, and logit.

		Transformation of infant mortality rate				
Period	Untrans-formed	Square root	Cube root	Log	Logit (limited)	Logit (extended)
1962-67	-0.47	-0.15	0.01	0.44	-0.08	0.04
1967-72	-0.44	-0.11	0.05	0.48	-0.22	-0.07
1972-77	-0.50	-0.08	0.11	0.58	-0.40	-0.19
1977-82	-0.61	-0.19	-0.01	0.48	-0.34	-0.14

Note: The limited transformation assumes a minimum infant mortality rate of 6. The extended transformation assumes a minimum of 3.

Table 10. Means and percentiles across countries of rate of change in logit of infant mortality rate and working estimates.

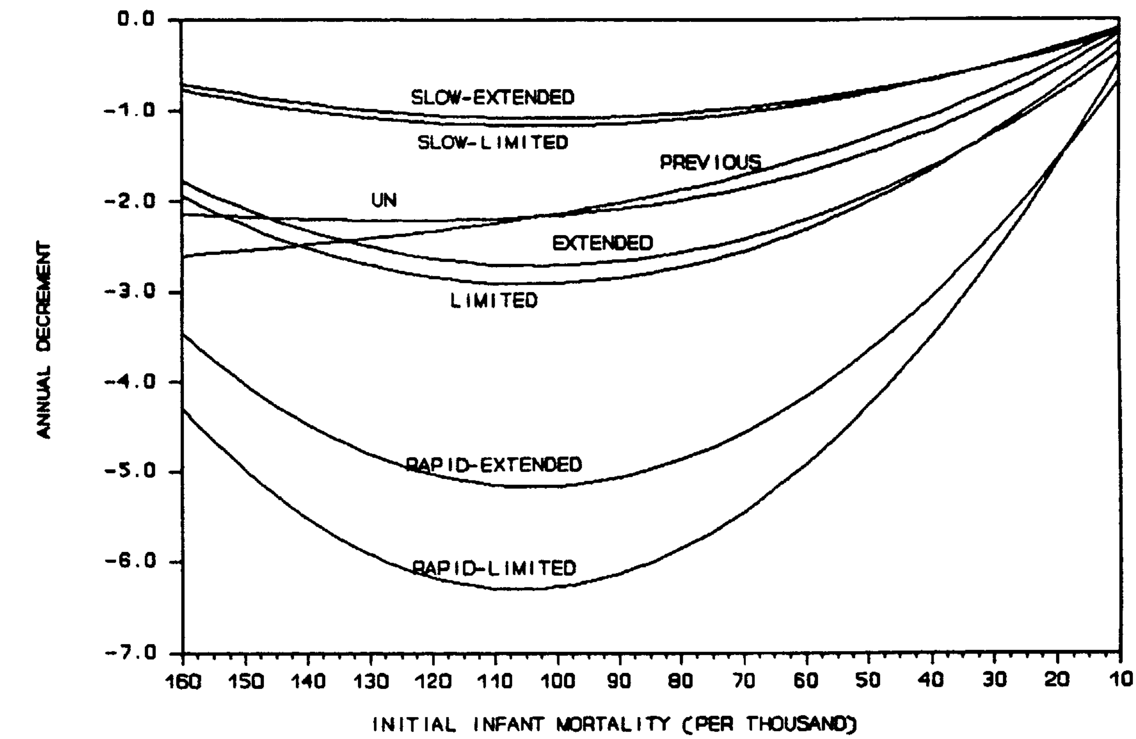
Transformation and data set	No. of cases	Mean	Percentile 90th	75th	50th	25th	10th
Limited							
Set A, 1962-67	73	0.065	0.025	0.043	0.056	0.088	0.111
Set A, 1967-72	81	0.064	0.021	0.038	0.062	0.085	0.104
Set A, 1972-77	72	0.085	0.041	0.049	0.076	0.117	0.141
Set A 1977-82	58	0.086	0.033	0.050	0.077	0.120	0.165
Set B, 1977-82	52	0.056	0.000	0.038	0.051	0.085	0.102
Combined	336	0.071	0.024	0.043	0.061	0.093	0.131
Extended							
Set A, 1962-67	73	0.061	0.025	0.039	0.051	0.078	0.102
Set A, 1967-72	81	0.059	0.021	0.035	0.056	0.077	0.090
Set A, 1972-77	72	0.073	0.036	0.048	0.068	0.094	0.112
Set A, 1977-82	58	0.068	0.029	0.040	0.053	0.089	0.125
Set B, 1977-82	52	0.046	0.000	0.037	0.050	0.073	0.093
Combined	336	0.062	0.022	0.041	0.055	0.080	0.104
Working estimates			Slow		Medium		Rapid
Limited			0.024		0.060		0.130
Extended			0.022		0.055		0.105

levels of infant mortality, from 20 per thousand or so down--a critical segment for long-run projections. The natural log, on the other hand, fits well at low levels, but does not eliminate the correlation between level and rate of change. A logit transformation similar to that for life expectancy did work better, reducing though not entirely eliminating the correlation between level and rate of change and fitting the data well at low levels.

The minimum and maximum for the logit were defined in the following way. Two minima were chosen, a "limited" alternative of 6 per thousand, roughly corresponding to the lowest infant mortality level, for men and women combined, in the Coale-Demeny (1983) West family life tables, and an "extended" alternative of 3 per thousand, roughly corresponding to the lowest level infant mortality would attain if the Coale-Demeny tables were extended to allow male and female life expectancies to reach the "extended" maxima used earlier. A maximum infant mortality rate of 200 per thousand was chosen. This allows infant mortality to fall most rapidly when it has reached about 100, which roughly corresponds to the level at which life expectancy should rise most rapidly.

Rates of change in the logit between quinquennia were calculated by country, and averages and percentiles for various periods are shown in Table 10: for set A countries, for each successive pair of quinquennia; and, for set B countries, for the change between 1975-80 and 1980-85. Averages vary across periods, appearing to rise over time in the set A data but being much lower for the set B data for the last period. Arguably, having better data, as the countries in set A do, is associated with faster reduction in infant mortality. Instead of defining a general pattern solely on the basis of set A data, therefore, we combined all the data in the last row of each section

Figure 2
Annual decrements to infant mortality rate per thousand from different models, assuming slow, medium, and rapid improvement



of Table 10. This forms the basis for working estimates in the same table of slow, medium, and rapid change.

What these patterns mean is illustrated in Table 11, which shows, for instance, that the infant mortality rate would indeed drop fastest from around 100, by between 1.2 and 6.3 points per thousand a year, as opposed to falling only .1 to .7 points a year once it has reached 10. However, the decline is fastest in percentage terms--over 4 percent by the medium model--from an infant mortality rate of around 30.

Figure 2 makes comparisons with the U.N. (1988a) and the previous World Bank (Zachariah and Vu 1988) patterns. Country by country decrements in infant mortality between 1985-90 and 1990-95 in these two sources were approximated with cubic equations, using initial infant mortality as the predictor, that fit quite well, giving R^2 of .86-.87. These equations are used to provide the curves in Figure 2. The decrements obtained here using the limited and extended transformations are larger than those in the U.N. or previous World Bank patterns, but never by more than one per thousand. The slow and rapid models provide a fairly wide interval around the medium estimates. This interval is not as wide as actually reported declines: developing countries with reliable data show a range of declines from 0 to more than 10 percent (U.N. 1988:129-131), whereas the working models allow declines no smaller than .6 percent and no larger than 8.5 percent. Nevertheless, where averages of reliable data have been taken, they fall close to the medium estimates. For 33 developed countries with initial infant mortality rates of 10 to 40 per

Table 11. Annual absolute and percentage changes in infant mortality rate, with different equations, from varying initial levels.

Initial level	Limited			Extended		
	Slow	Medium	Rapid	Slow	Medium	Rapid
Absolute change						
150	-0.9	-2.3	-5.0	-0.8	-2.1	-4.0
125	-1.1	-2.8	-6.1	-1.0	-2.6	-4.9
100	-1.2	-2.9	-6.3	-1.1	-2.7	-5.2
75	-1.1	-2.6	-5.7	-1.0	-2.5	-4.7
50	-0.8	-2.0	-4.3	-0.8	-1.9	-3.7
25	-0.4	-1.0	-2.1	-0.4	-1.1	-2.0
10	-0.1	-0.2	-0.5	-0.1	-0.4	-0.7
Percentage decline						
150	0.6	1.5	3.3	0.6	1.4	2.7
125	0.9	2.2	4.8	0.8	2.1	3.9
100	1.2	2.9	6.3	1.1	2.7	5.2
75	1.4	3.5	7.6	1.3	3.3	6.3
50	1.6	4.0	8.5	1.6	3.9	7.3
25	1.6	4.0	8.5	1.7	4.2	7.9
10	0.9	2.3	4.8	1.5	3.6	6.8

thousand, the average decline in 1975-80 was 4.9 percent, slightly above the medium estimates. For 34 developed countries with initial rates of 7 to 30, the average decline in 1980-84 was 3.6 percent, essentially identical to the medium estimates.

Predicting specific trends. As with life expectancy, the rate of change in infant mortality is related to its rate of change in a previous period. Table 12 shows that the correlation

Table 12. Correlations between rate of change in log of infant mortality rate and rate of change in preceding periods.

Preceding period	Limited			Extended		
	1967-72	1972-77	1977-82	1967-72	1972-77	1977-82
Previous period	0.52	0.47	0.44	0.54	0.46	0.38
Period twice removed		0.33	0.36		0.32	0.21
Period thrice removed			0.16			0.15

Table 13. Regressions for rate of change in logit of infant mortality rate on previous rate of change in logit.

Transformation and period predicted	B	(t)	Constant	R^2	N
Limited					
1967-72	0.5367	4.67	0.0298	0.25	61
1972-77	0.6467	4.13	0.0403	0.21	60
1977-82	0.4961	3.49	0.0438	0.18	52
All periods	0.5608	7.36	0.0369	0.23	175
Extended					
1967-72	0.5328	4.97	0.0263	0.28	61
1972-77	0.5531	4.03	0.0362	0.20	60
1977-82	0.4355	2.95	0.0379	0.12	54
All periods	0.5050	6.82	0.0331	0.20	177
Working equations					
Limited	0.5		0.03		
Extended	0.5		0.0275		

is stronger the closer the two periods are, and becomes quite weak after 15 years or so.

Regressions were run to predict the rate of change in the logit of infant mortality with set A data, using the previous rate of change and the same socioeconomic indicators used earlier. Six regressions were run in all, for three periods and for both limited and extended transformations. The female primary and secondary enrolment ratios and GNP per capita had significant effects, but only in one regression each. None of the other socioeconomic variables had a significant effect. On the other hand, the rate of change in the logit of life expectancy in the previous period had a significant effect in each regression. Table 13 shows regressions using only the previous rate of change as a predictor. Working equations, based on these regressions, can be defined so that, relative to preceding rates, predicted rates converge toward the previously defined medium rates when the equations are applied for successive periods.

Projection approach. An approach to projecting infant mortality can be devised from these results. First, predict rate of change from the working models in Table 13, with the rate of change for each period predicted from the rate for the previous period. Apply this process for 15 years, requiring that the predicted rates fall within the limits described as slow and rapid decline. Second, for the longer term, either apply the medium decline pattern or derive the infant mortality rate from model life tables chosen on the basis of life expectancies. As with life expectancy, either the limited or extended results can be used.

AGE PATTERNS OF MORTALITY

No analysis was done of age patterns of mortality beyond age 1. In order to provide such patterns for projection purposes, one can rely on previously estimated model life tables. One approach, using the Coale-Demeny (1983) model life tables, is outlined here, and consistency

Table 14. Regressions for maximum allowable rate of change in logit of infant mortality rate (standard errors in parentheses).

Predictor	(1)	(2)	(3)	(4)
Constant	0.01	0.05	0.10	0.15
	(0.01)	(0.01)	(0.01)	(0.00)
Change in e_0	-2.29	-2.12	-2.37	-2.45
	(0.33)	(0.28)	(0.19)	(0.12)
e_0 (both sexes)		-8.6E-04	-1.4E-03	-1.8E-03
		(2.3E-04)	(1.8E-04)	(1.3E-04)
Infant mortality			-2.3E-04	-9.0E-04
			(3.8E-05)	(1.1E-04)
Infant mortality^2				3.0E-06
				(5.0E-07)
R^2	0.64	0.76	0.90	0.96

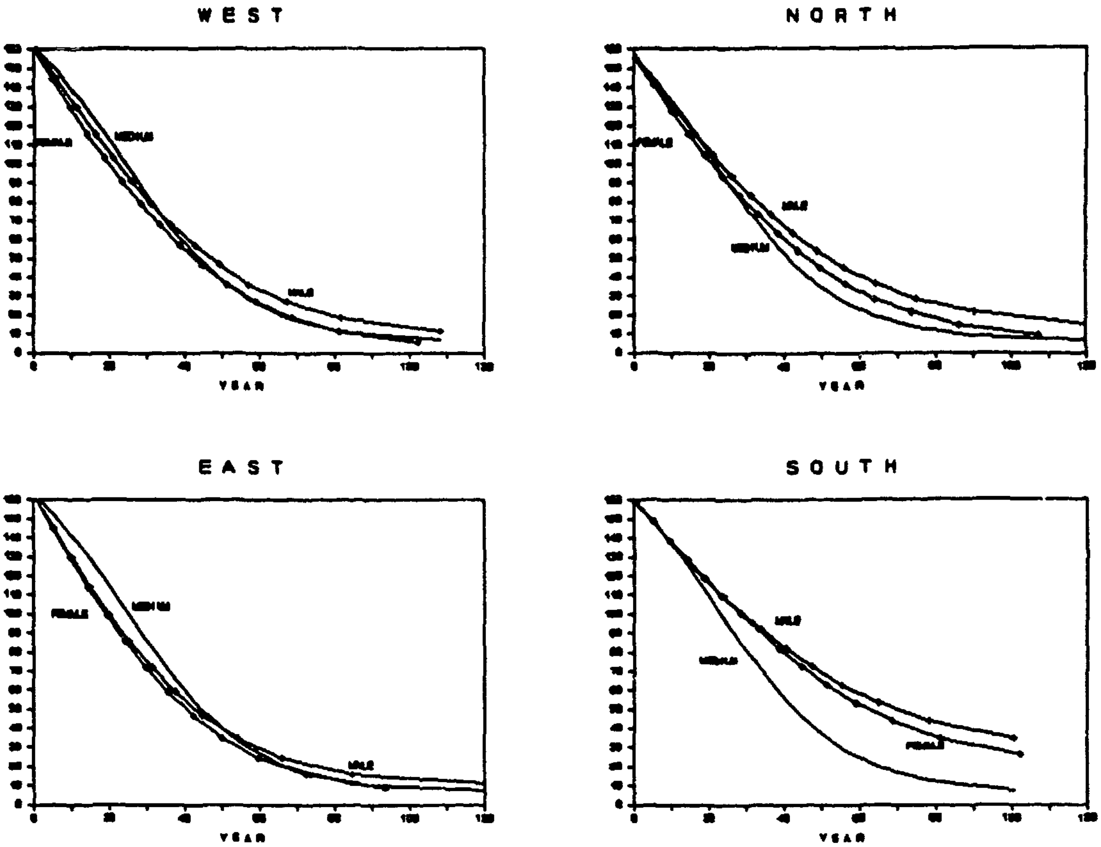
between projected infant mortality and infant mortality derived from model life tables is considered.

For each projection period, estimated male and female life expectancies can be used to identify the appropriate levels for males and females of each Coale-Demeny life table family. The estimated infant mortality rate usually implies different levels. The maximum convergence between the levels implied by life expectancy and infant mortality can be used to select one of the four life table families. Alternatively, if good information on child mortality is available, it can be used in conjunction with infant mortality to choose a life table family. Working within the chosen family, one can then produce a "split" life table, combining different levels, to give exactly the desired infant mortality and life expectancy. First, choose the level that matches the infant mortality rate, adopting the consequent age pattern of mortality for the childhood years (up to age 9 or 14, as desired). Second, choose another level to give the age pattern of mortality for older ages such that life expectancies, given the combined segments of the two life tables, match the projected values.

If country-specific mortality trends are projected for three periods, split life tables could be produced for at least that long. Once the country-specific trend is replaced by a universal trend, it becomes more reasonable to adopt a universal age pattern. One can use projected life expectancies to choose appropriate levels of the Coale-Demeny West family, the most general of the four families. Several projection periods should be allowed for a gradual shift from some other family to the West family.

Whether split or unified life tables are used, the consistency of projected infant mortality can become a problem. When split life tables are used, projected infant mortality can be exactly duplicated. In principle, however, it could fall so fast, relative to the rise in life expectancy, that adult mortality would have to rise. This is seldom desirable, and to prevent it a

Figure 3
Infant mortality medium trend compared with trends when model life tables are chosen to match medium male or female life expectancy trends



maximum allowable increase for infant mortality can be established. We estimated what rate of change in the logit of infant mortality would prevent life expectancy at age 15 (e_{15}) from declining at any point over three quinquennia, assuming West model life tables and given different values of the current infant mortality rate, the current male and female combined e_0, and the current rate of change in combined e_0. About 30 estimates of this maximum were regressed on the other variables, with results shown in Table 14. (This exercise was actually performed using a minimum infant mortality rate, for purposes of estimating the logit, of 4, intermediate between the limited and the extended minima.) The allowable maximum change in infant mortality varied most strongly with the rate of change in life expectancy, but was also affected by current levels of life expectancy and infant mortality, the latter having a nonlinear effect. The final equation incorporating all these effects attained an R^2 of .96. This equation does in fact still allow a rise in adult mortality in specific circumstances if other life table families are applied, but it substantially moderates any such increase.

When unified life tables are used, projected infant mortality is not exactly duplicated but is approximated. The choice of successive life tables from the life expectancy trends imposes a trend on infant mortality. Figure 3 shows that the imposed trend is in fact quite close to the medium trend for infant mortality estimated earlier. From an assumed infant mortality rate of 160 in year 0, the curve described by the medium trend in life expectancy closely parallels the curves described if life table levels are chosen successively (based either on the male or on the female medium life expectancy trend) within the West family--though not necessarily if other life table families are used. Results are shown for the limited transformation; results for the extended transformation are similar.

ILLUSTRATIVE PROJECTIONS

Some results from applying the projection approaches described will be presented and contrasted with results from other procedures. First we specify the contrasting procedures, and then we discuss results for eight countries with current life expectancies varying from 52.5 to 76.8 years: Zaire, Bolivia, Ghana, Pakistan, Thailand, Poland, Costa Rica, and Norway.

Procedures used. "New" projections using essentially the procedures described above will be contrasted with "old" projections using the World Bank procedures covered in the literature review and with results from the latest U.N. (1989) assessment. Between the new and the old projections, base populations, initial estimates of vital rates, and trends for fertility and migration are identical. Only mortality trends differ. The U.N. projections are potentially different from the new and the old projections not only in mortality trends but also in other respects.

For the new projections, we used the limited transformations described above, because the life tables necessary for the extended transformations are not now available. The 1985-90 quinquennium was taken as the base period. Using estimates of 1980-85 life expectancies and education data drawn from World Bank files, rates of change in male and female life expectancies were estimated from the "all periods" equations in Table 6. Adjustments to these rates were made as necessary to keep them within the limits described earlier, in order to prevent too rapid or too slow change or too great a discordance between male and female rates of change. These rates of change were applied for one period, and rates for the two following periods were estimated from the working equations in Table 8. For subsequent periods, rates of change were assumed to be equal to the medium working estimates in Table 2. Rates of change in infant mortality were estimated from the working equations in Table 13, but were required to stay within limits previously described. Life tables were chosen from the Coale-Demeny (1983) set. For the first three quinquennia, the life tables were split at age 15 (using a Fortran program called Split), one segment being chosen to give the estimated infant mortality rate and the other segment being chosen to give the estimated life expectancy. The life table family chosen was the one that minimized the divergence in levels across the split. For subsequent quinquennia, life expectancies alone were used to choose unified life tables, and the West family was always applied.

A cohort-component population projection program developed for the World Bank called ProjPC (Hill n.d.) was used. This program allows the specification of mortality parameters for arbitrarily selected periods, interpolating linearly to obtain mortality assumptions for other periods. We specified survivorship ratios for the base quinquennium and the next three quinquennia, and then for 2025-30, 2050-55, and 2100-2105. This allowed the program to interpolate and to shift smoothly from whatever life table family was initially chosen to the West family.

To complement the new projections, which give a medium trend, projections of slow and rapid improvements in mortality were also made. For rapid mortality decline, rates of increase in life expectancy were raised by half, and rates of decline in infant mortality doubled. (Initial rates that are close to the medium working estimates in Table 2 would by these calculations become almost equal to the rapid working estimates.) These calculations were done for the first three periods. For subsequent periods, the rates of change in life expectancy were assumed to equal the rapid working estimates. For slow mortality decline, rates of increase in life expectancy and rates of decrease in infant mortality are cut in half for three periods, and the slow working estimates for life expectancy applied subsequently.

Note that neither the new nor the old projections correspond exactly to the standard World Bank projections. The new projections incorporate some features not so far used in the World Bank projections, and the old projections incorporate updates of base-period data and of projected trends in fertility and migration.

Results. Comparisons of life expectancy, infant mortality, and total population trends will be discussed, and some reference will be made to other population parameters.

Figure 4 shows five alternative projections of life expectancy trends in each of the eight countries, using the new, old, U.N., rapid, and slow patterns. The new and old patterns are relatively close: for all of the countries for most periods, the new estimates are within 2 percent of the old estimates, and are sometimes above and sometimes below them. The biggest differences are for Ghana and Bolivia about 25 years into the future, when the new estimates are 4 or 5 percent lower because they take into account the slowness of past improvements in life expectancy in these two countries. The new estimates are also close to the U.N. patterns for half of the countries, those with higher mortality. For Costa Rica, the U.N.'s initial estimate is higher but the U.N. trend is for slower improvement. For Thailand, Poland, and especially Norway, the U.N. projects faster improvement. One reason for these differences is the use of the limited transformation, which means that life expectancy in the new projections cannot rise as high as the U.N. model allows. The rapid and slow patterns generally provide an envelop within which most of the other projections fall, except at the highest levels of life expectancy. Life expectancy is shown for both sexes combined; comparisons by sex lead to similar conclusions.

For infant mortality (Figure 5), greater divergence among the patterns appears. This is because the old Bank procedures used current infant mortality rates derived from model life tables, rather than attempting to match reported rates. Relative to the old rates for the base period, the new rates are as much as 40 percent higher or lower. Similar variation exists for future periods. However, for no country are the new estimates continuously higher or lower than the old estimates: for Thailand, for instance, the new estimate is 40 percent lower than the old estimate for 2050 but 30 percent higher than the old estimate for 2100. The new pattern, because it is based on the limited transformation, does not allow infant mortality to fall as low as in the U.N. estimates.

These variations in mortality assumptions allow the new crude death rate estimates to vary by 10 percent up or down relative to the old estimates, except for Ghana and Bolivia, which show greater variation. Variation in probability of dying by age 5 (q_5) and expectation of life at age 10 (e_{10}) were also examined. Comparisons of the former resemble comparisons of infant mortality trends, and comparisons of the latter resemble comparisons of life expectancy at birth.

The consequences for total population are shown in Figure 6, which expresses the new estimates as a percentage of the old. The largest changes in population between the two sets of projections are a reduction of 2.5 percent and an increase of 1.7 percent. These changes may not be entirely negligible, but they are small. For Ghana, a 5 percent maximum reduction in life expectancy, relative to the old estimates, translates into a 20 percent maximum increase in the crude death rate, and eventually, after a lag of some decades, a 2.5 percent maximum decrease in the population, also relative to the old estimates. Changes in the assumed mortality trend, as measured by these indicators, translate into delayed and considerably less than proportional changes in total

Figure 4
Life expectancy in years projected by different models, selected countries, 1985-2100

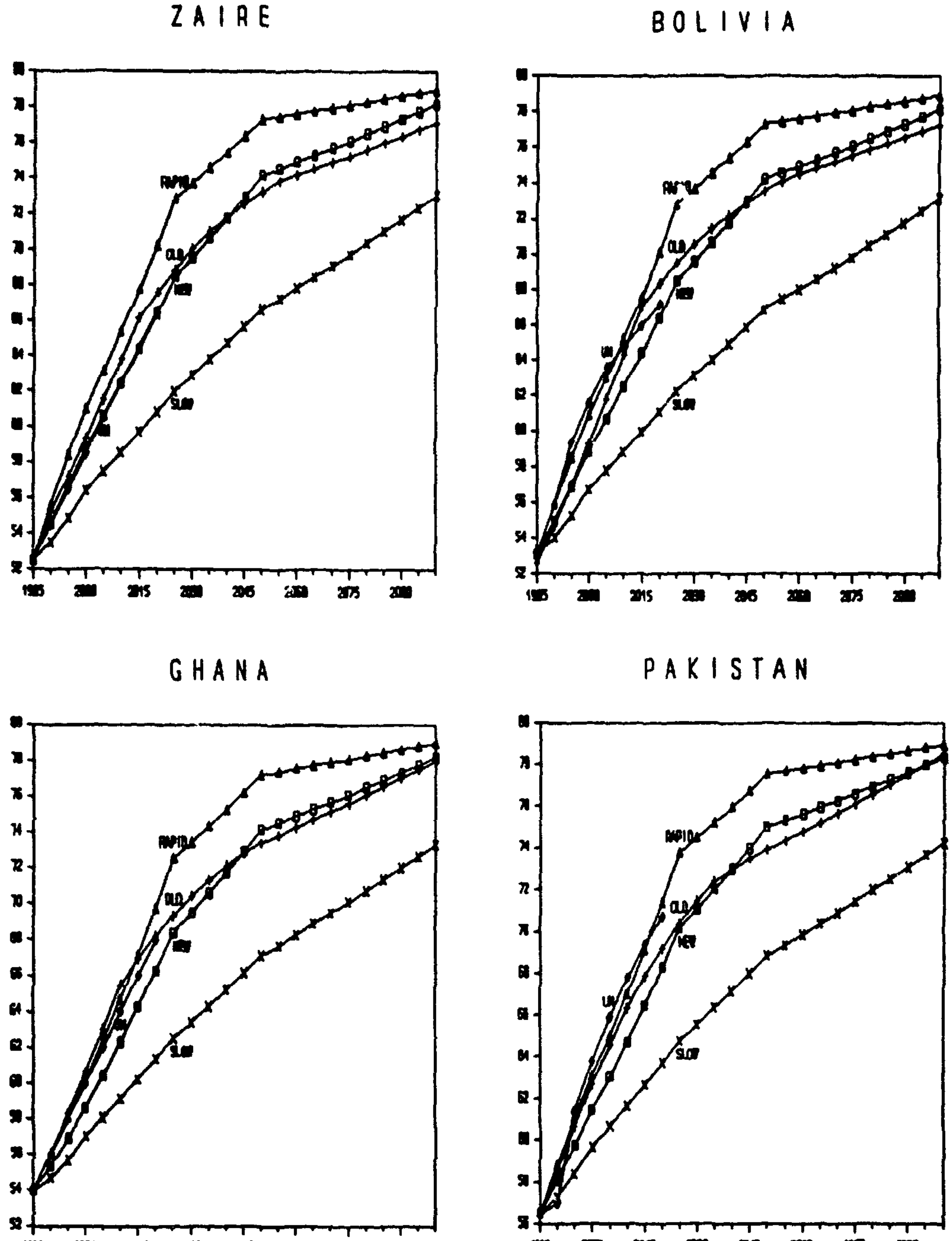


Figure 4 (continued)
Life expectancy in years projected by different models, selected countries, 1985-2100

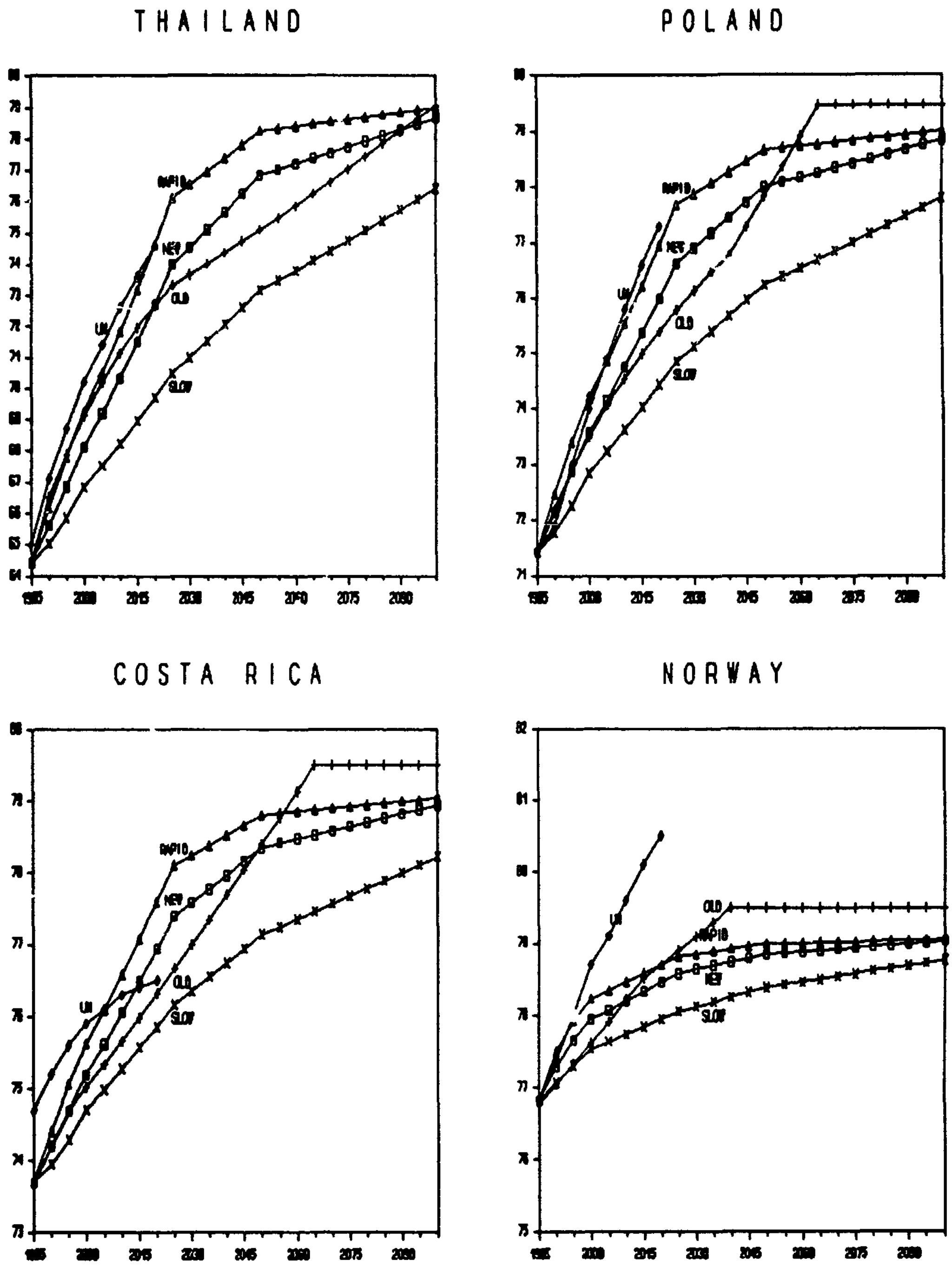


Figure 5
Infant mortality rate per thousand projected by different models, selected countries, 1985-2100

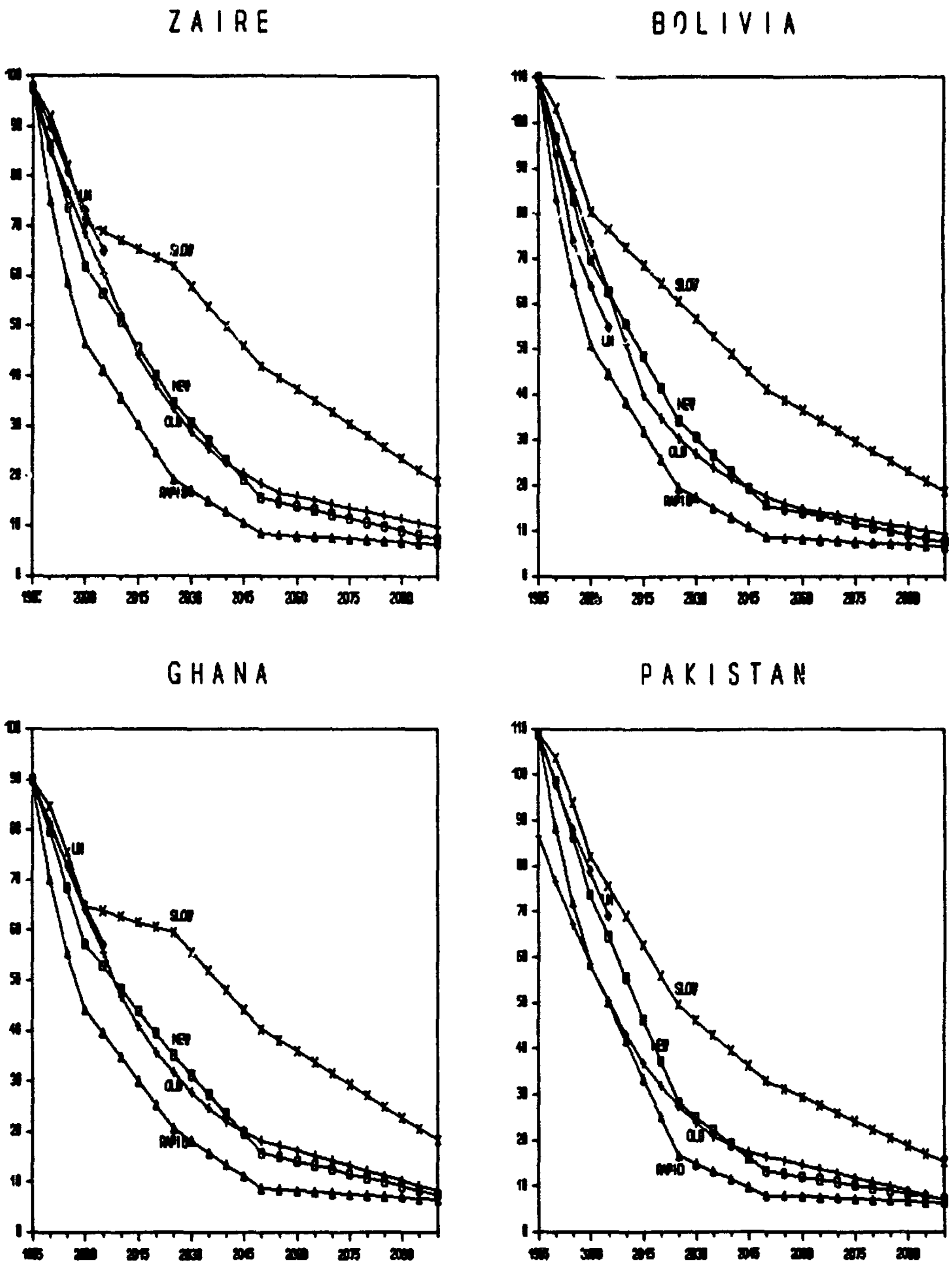


Figure 5 (continued)
Infant mortality rate per thousand projected by different models, selected countries, 1985-2100

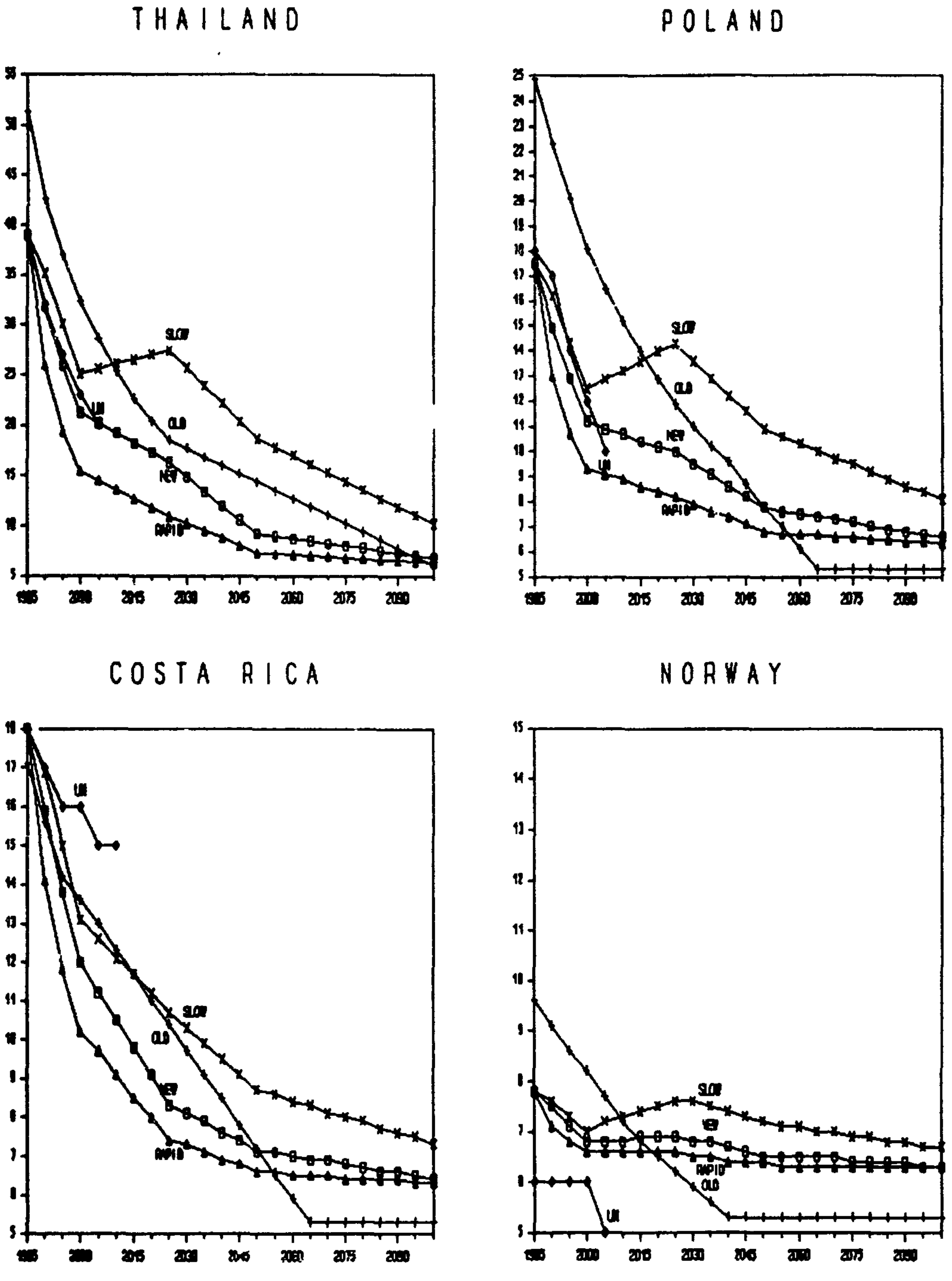
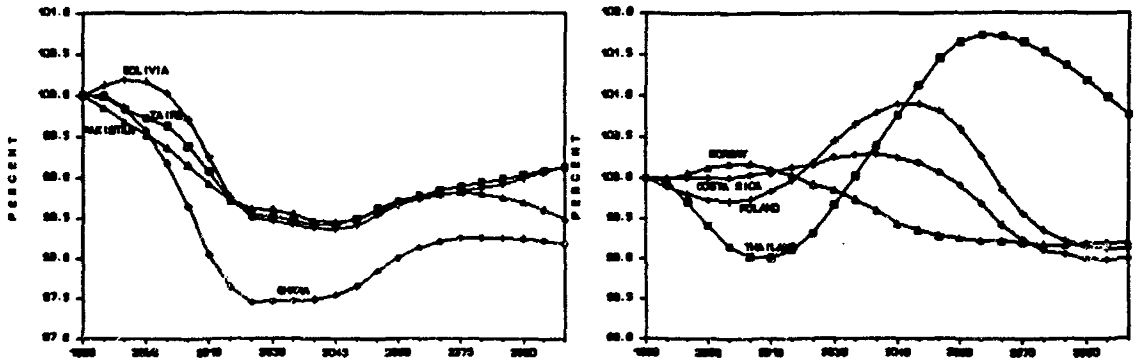


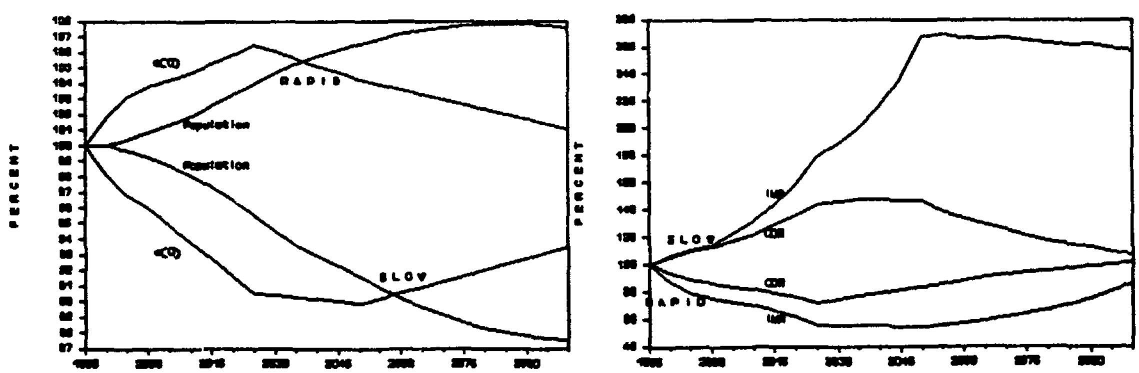
Figure 6
Total population using new mortality pattern as a percentage of population using old mortality pattern, selected countries, 1985-2100



population. Nor are the age structures of populations greatly different between the new and the old projections: dependency ratios resemble each other, as population totals do.

More drastic changes in mortality assumptions, such as those represented by the rapid and slow mortality decline patterns, can produce larger variations in population, particularly for higher-mortality countries. (In the long run, life expectancy in the rapid, medium, and slow patterns must converge at the predefined upper limit. Therefore, differences among the mortality assumptions in these projections become greater for a period of 60 or so years at most, after which they slowly disappear.) The situation of Zaire is represented in Figure 7. Relative to the new medium mortality decline pattern, the rapid decline pattern allows life expectancy to be up to 6 percent higher within the 1985-2100 period, the crude death rate up to 30 percent lower, and the infant mortality rate up to 50 percent lower. As a result, population is as much as 8 percent higher

Figure 7
Life expectancy, infant mortality, crude death rate, and total population under rapid and slow mortality decline, as percentages of parallel estimates under medium mortality decline, Zaire, 1985-2100



given rapid mortality decline rather than medium mortality decline. The slow decline pattern allows life expectancy to be up to 10 percent lower than under medium mortality decline, the crude death rate up to 50 percent higher, and the infant mortality rate up to 170 percent higher. Population will be up to 13 percent lower under slow mortality decline than under medium mortality decline.

CONCLUSION

Procedures for short-run and long-run projections of mortality applicable to all countries of the world have been devised based on analysis of recent mortality trends. These procedures involve calculating rates of change for and separately projecting male and female life expectancy and infant mortality and then selecting appropriate model life tables.

The procedures were to have been based on relatively reliable estimates of life expectancy and infant mortality. However, comparisons of such estimates with other estimates based on weaker data indicated consistent differences: better estimates of life expectancy showed slower improvements than other estimates, and better estimates of infant mortality showed faster improvements than other estimates. Because reasons could be adduced for these differences, the procedures were ultimately based on all the assembled data rather than solely on the better data.

Attempts to predict change in life expectancy and infant mortality from socioeconomic variables were minimally successful. To a large extent, it can be argued, socioeconomic variables add little predictive power if previous trends in these variables--themselves conceivably dependent on socioeconomic factors--are taken into account. The procedures finally devised involve predicting country-specific trends in mortality for 15 years (beyond which current mortality trends have little influence) and then imposing a uniform mortality trend.

Comparisons of the procedures with previous World Bank procedures and with U.N. procedures for projecting mortality indicate that life expectancy trends are quite similar. Infant mortality trends differ more. The derived procedures allow infant mortality to fall somewhat faster overall, and result in greater contrast with previous Bank projections than is the case for life expectancy. The effect on total population of switching from the previous procedures to these derived ones is small.

Assessment of the adequacy of these procedures involves two issues: how well past trends are represented and how accurately future trends are forecasted. Past trends are represented by data that is somewhat uncertain for developing countries, and that may undergo revision in the future. Alternative approaches to representing past trends are also possible, and could be as satisfactory statistically while implying different future trends. The current representation does reflect available data and might be taken to provide standards for judging mortality improvement in different countries, but cannot be considered definitive as both data and approaches will evolve in the future.

How accurately these procedures forecast future trends will not be known for some time. The critical assumption in this exercise, that future trends will resemble what we know of past trends, will undoubtedly not be universally true. For instance, the spread of Human Immunodeficiency Virus infection is not reflected in the data, and therefore is not factored into the derived procedures. As this spread should have important impact on mortality in particular countries, adjustments to the mortality trend may be called for. Without adequate data, we have not considered this issue here. Other uncertainties regarding future mortality trends also exist, such as uncertainty about the ultimate limits to life expectancy. This exercise cannot resolve such uncertainty; instead, it provides a perspective on what the future could be like if it resembled the more certain past.

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