The International Union for the Scientific Study of Population Problems was set up in 1928, with Dr Raymond Pearl as President. At that time the Union's main purpose was to promote international scientific co-operation to study the various aspects of population problems, through national committees and through its members themselves. In 1947 the International Union for the Scientific Study of Population (IUSSP) was reconstituted into its present form.

It expanded its activities to:

- stimulate research on population
- develop interest in demographic matters among governments, national and international organizations, scientific bodies, and the general public
- foster relations between people involved in population studies
- disseminate scientific knowledge on population

The principal ways through which the IUSSP currently achieves its aims are:

- organization of worldwide or regional conferences
- operations of Scientific Committees under the auspices of the Council
- organization of training courses
- publication of conference proceedings and committee reports.

Demography can be defined by its field of study and its analytical methods. Accordingly, it can be regarded as the scientific study of human populations primarily with respect to their size, their structure, and their development. For reasons which are related to the history of the discipline, the demographic method is essentially inductive: progress in knowledge results from the improvement of observation, the sophistication of measurement methods, and the search for regularities and stable factors leading to the formulation of explanatory models. In conclusion, the three objectives of demographic analysis are to describe, measure, and analyse.

International Studies in Demography is the outcome of an agreement concluded by the IUSSP and the Oxford University Press. The joint series is expected to reflect the broad range of the Union's activities and is based on the seminars and the work of the committees organized by the Union.

Health and Mortality Among Elderly Populations

Edited by

Graziella Caselli
and
Alan D. Lopez

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diminish, this ageing of populations is increasingly affected by previous declines in mortality among adults and the continuing decrease in mortality at older ages. The second major consideration is the transformation that is occurring in patterns of disease and impairment among the old. The third comprises a range of important developments in the socio-economic characteristics of older people, for example, with regard to their income, housing, education, and family circumstances. These new trends pose a challenge for the organization and financing of formal care, and also require a radical change in the integration of the elderly into society. They also served to define the objectives of the Sendai seminar.

Another purpose of the seminar was to facilitate an interdisciplinary debate about these issues and to review the prospects for further advances in health status among the elderly. The seminar was attended by over sixty participants representing a range of academic disciplines including demography, gerontology, epidemiology, sociology, and other social sciences.

The success of the seminar owes much to the efforts of S. Kono, who served as a most effective liaison between the Committee and the Japanese hosts. The very generous financial support and hospitality of the City of Sendai and the Japanese Aging Research Centre, who co-sponsored the seminar along with the United Nations and the World Health Organization, is gratefully acknowledged. The editors also wish to acknowledge the assistance of the IUSSP Secretariat, particularly Mr M. Lebrun, Mrs M.-C. von Rulach, and Mrs M. Jaan Crowley for their splendid work in preparing this manuscript for publication.

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13 Mortality Projections for Japan: *A Comparison of Four Methods*

JOHN R. WILMOTH

13.1. Introduction

Death-rates at all ages have fallen with an astonishing speed over the past 40 years in Japan. Life expectancy at birth among the Japanese is now the highest in the world for any national population. While most people agree on the advantages of a longer life for the individuals who benefit from it, there is increasing concern, in Japan as elsewhere, about an important side-effect of rapid mortality decline, namely, population ageing. All analysts agree that populations in developed countries like Japan will continue to grow older (whether measured by the median age of the population, the percentage over age 65, or some other indicator), but the extent and speed of this transformation over the next 30–50 years are somewhat less certain and depend, to a large extent, on future trends in death-rates at older ages (Horiuchi, 1991).

In this chapter, trends in death-rates for total and cause-specific mortality for Japan are examined in an attempt to forecast the future level and pattern of Japanese mortality. In particular, an attempt is made to answer the following questions: 'Will life expectancy continue to rise in Japan, or will it reach an upper limit?' 'How will the proportion of the Japanese population that is older than age 65 (or 85) change in the future?' 'What causes of death will have the greatest influence on trends in total death rates?' In the process of making these evaluations, two important methodological questions arise: first, what difference does it make for our mortality forecasts if we make separate projections by cause of death, as opposed to a single projection for total mortality? And secondly, what difference does it make if we consider trends in Japanese mortality only during the period after 1950, for which relatively accurate and abundant data are available, as opposed to a longer time-frame?

The projection methods employed here are adaptations of the procedure proposed by Ronald Lee and Lawrence Carter. In the words of the authors, their procedure 'combines a rich yet parsimonious demographic model with statistical time series methods' (Lee and Carter, 1992: 659). This method has been applied to both total and cause-specific mortality, although it was originally proposed for total mortality only. Some modifications to the original

procedure, described later in this chapter, were necessary in order to make the extension to mortality by cause and in light of the unusual historical pattern of mortality decline in Japan.

The first section of this chapter provides an overview of the Lee–Carter forecasting procedure. Forecasts of total mortality based on Japanese data for 1951–90 are then presented, followed by forecasts of total mortality based on a comparison with mortality trends in Sweden and, finally, forecasts of cause-specific mortality based on Japanese data for 1955–90. The technical details of the forecasting procedures used in this chapter are described in detail elsewhere (Wilmoth, 1993).

The Lee–Carter Procedure

The procedure proposed by Lee and Carter for forecasting mortality relies, first, on a simple model of past mortality trends. This model can be written as follows:

$$f_{xt} = \ln(m_x) = a_x + b_x k_t + \varepsilon_{xt} \tag{1}$$

where m_{xt} is the observed age-specific death-rate at age x during time t; a_x, b_x, and k_t are the model's parameters; and ε_{xt} is an error term. When the model is fit by ordinary least squares (OLS), the interpretation of the parameters is quite simple: the fitted values of a_x exactly equal the average of $\ln(m_{xt})$ at age x over time, b_x represents the age-specific pattern of mortality change, and k_t represents the time trend. The units on b_x and k_t are arbitrary, since one of these two elements could be multiplied by a constant while the other one is divided by the same constant without altering the predicted values given by the model. In this chapter, the standard normalizing constraint on b_x is used, namely, that $\sum_x b_x^2 = 1$. For full model identification, it is also necessary that $\sum_t k_t = 0$. Given these constraints, the model can be fitted by minimizing the sum of squared errors, that is, by minimizing

$$\sum_{xt} (f_{xt} - a_x - b_x k_t)^2 \tag{2}$$

This model of mortality change has been used as the basis for all forecasts presented in this chapter, although an important modification has been made in the fitting procedure. Lee and Carter proposed this method for use in forecasting total mortality, but it has also been used here to forecast trends in mortality by cause of death. Since some cause-specific death-rates are zero at certain ages (for example, children and young adults do not die of 'senility'), the fitting procedure in these cases had to be modified in order to avoid taking logarithms of zero death-rates. The fitting procedures used in this chapter rely on weighted least squares (WLS) rather than ordinary least squares (OLS), the technique used by Lee and Carter. The weights used in fitting the model always equal the observed number of deaths in each cell of the data matrix.[1] Therefore, the weights are zero when $m_{xt} = 0$, so an arbitrary value can be assigned to f_{xt} in this situation without affecting the results. The WLS technique has other advantages in addition to avoiding the 'zero-cell' problem. For example, when fitted by WLS the Lee–Carter model reproduces summary indicators of mortality, such as life expectancy at birth, almost perfectly (Wilmoth, 1993). This model was applied separately to male and female mortality in Japan during the period 1951–90.[2]

The results of this exercise are shown in Table 13.1 and Figure 13.1. For purposes of interpretation, it is easiest to write the model as follows:

$$\hat{m}_{xt} = \hat{A}_x \hat{B}_x^{\hat{k}_t} \tag{3}$$

where $A_x = e^{a_x}$, $B_x = e^{b_x}$, and the carat symbol ^ denotes fitted (or predicted) values given by the model. Thus, when $\hat{k}_t$ equals zero, as occurs around 1971 for both men and women (see Figure 13.1), the predicted age-pattern of mortality is exactly $\hat{A}_x$, as shown in Table 13.1. For every one-unit change in $\hat{k}_t$, the predicted age-specific death rate, $\hat{m}_{xt}$, changes by a factor of $\hat{B}_x$. Mortality change has been more rapid at younger than at older ages, and therefore the values of $\hat{B}_x$ in Table 13.1 vary across the age-range in the expected fashion. The model thus captures the gradual transformation in the shape of the mortality curve over time.

13.2. Method I: Total Mortality, Baseline 1951–90

For purposes of forecasting, the appeal of the model in equations 1 or 3 is well illustrated by Figure 13.1. Here, the pattern of mortality change over time is captured by a single parameter, the mortality index k_t, and this parameter follows a nearly linear trend during 1951–90. The near-linearity in estimated values of k_t reflects the fact that the exponential rate of decay in observed age-specific mortality rates has been nearly constant over this time-period, although the magnitude of that rate has differed by age, as reflected in values of $\hat{b}_x$ or $\hat{B}_x$ in Table 13.1. The pace of mortality decline has been more rapid for women than for men, and this fact is reflected in the different slopes of the two estimated k_t trends. Both trends are close to linear, and therefore the Lee–Carter procedure derives forecasts of future mortality rates simply by linear extrapolation of these trends.

The observed trend in estimated k_t was modelled as a random walk with a linear drift term, as suggested by Lee and Carter. In other words, after subtracting out the linear trend in k_t, the residuals are modelled as a random walk, which moves up or down as the result of a series of independent and identically distributed random shocks. The appropriateness of this model was assessed using standard diagnostic procedures (Box and Jenkins, 1976). The resulting extrapolation of k_t is shown (for women only) in Figure 13.1, along with 95-per-cent confidence intervals.[3]

Once the projected values of k_t are available, it is a simple matter to obtain projected values of age-specific death-rates, life expectancy, and other life-table quantities. The implicit assumption here is that the age-dependent pattern of mortality decline observed in the past will continue into the future. Thus, projected values of m_{xt} are obtained based on equation 3, where the values of $\hat{A}_x$ and $\hat{B}_x$ are the same as before (see Table 13.1), but values of $\hat{k}_t$ are

[1] Choosing weights equal to the number of deaths associated with each age-specific death-rate is the appropriate choice from a statistical point of view as well, since the variance of $\ln(m_{xt})$ is approximately $1/D_{xt}$, where D_{xt} equals the number of deaths at age x and time t (Wilmoth, 1993).

[2] In this chapter, all mortality rates for Japan after 1951 were calculated by the author. Death counts for total mortality were taken from vital statistics publications; population figures were taken from census publications. Tabulations of deaths by cause were supplied by Shigemi Kono and then translated into cause-specific death rates by the author.

Table 13.1. Fitted parameters of the Lee-Carter mortality forecasting model: Total mortality, Japanese women and men, 1951–1990

Age x	Women				Men			
	$\hat{a}_x$	$\hat{b}_x$	$\hat{A}_x = e^{\hat{a}_x}$	$\hat{B}_x = e^{\hat{b}_x}$	$\hat{a}_x$	$\hat{b}_x$	$\hat{A}_x = e^{\hat{a}_x}$	$\hat{B}_x = e^{\hat{b}_x}$
0	−4.368	0.320	0.01268	1.38	−4.155	0.399	0.01569	1.49
1–4	−6.849	0.409	0.00106	1.50	−6.626	0.471	0.00133	1.60
5–9	−7.868	0.319	0.00038	1.38	−7.462	0.342	0.00057	1.41
10–14	−8.269	0.261	0.00026	1.30	−7.880	0.269	0.00038	1.31
15–19	−7.690	0.254	0.00046	1.29	−6.929	0.156	0.00098	1.17
20–4	−7.243	0.294	0.00072	1.34	−6.597	0.246	0.00136	1.28
25–9	−7.055	0.289	0.00086	1.34	−6.558	0.270	0.00142	1.31
30–4	−6.839	0.258	0.00107	1.29	−6.423	0.240	0.00162	1.27
35–9	−6.539	0.215	0.00145	1.24	−6.100	0.194	0.00224	1.21
40–4	−6.190	0.181	0.00205	1.20	−5.706	0.155	0.00333	1.17
45–9	−5.789	0.164	0.00306	1.18	−5.275	0.135	0.00512	1.14
50–4	−5.371	0.156	0.00465	1.17	−4.829	0.127	0.00799	1.14
55–9	−4.965	0.155	0.00698	1.17	−4.368	0.135	0.01267	1.14
60–4	−4.505	0.152	0.01106	1.16	−3.912	0.146	0.02000	1.16
65–9	−3.979	0.150	0.01871	1.16	−3.422	0.147	0.03264	1.16
70–4	−3.405	0.141	0.03320	1.15	−2.916	0.136	0.05417	1.15
75–9	−2.818	0.122	0.05971	1.13	−2.418	0.116	0.08907	1.12
80–4	−2.248	0.101	0.10561	1.11	−1.945	0.098	0.14298	1.10
85–9	−1.741	0.082	0.17527	1.09	−1.523	0.084	0.21816	1.09
90–4	−1.297	0.068	0.27336	1.07	−1.150	0.074	0.31663	1.08
95–9	−0.931	0.055	0.39413	1.06	−0.849	0.056	0.42801	1.06
100+	−0.653	0.038	0.52036	1.04	−0.613	0.002	0.54175	1.00

[3] The confidence intervals presented in this chapter include both the uncertainty from the random walk process and from estimation of the drift term, but ignore the uncertainty due to estimation of the parameters of the underlying model. See Appendix B of Lee and Carter (1992) for a detailed discussion and justification of this choice.

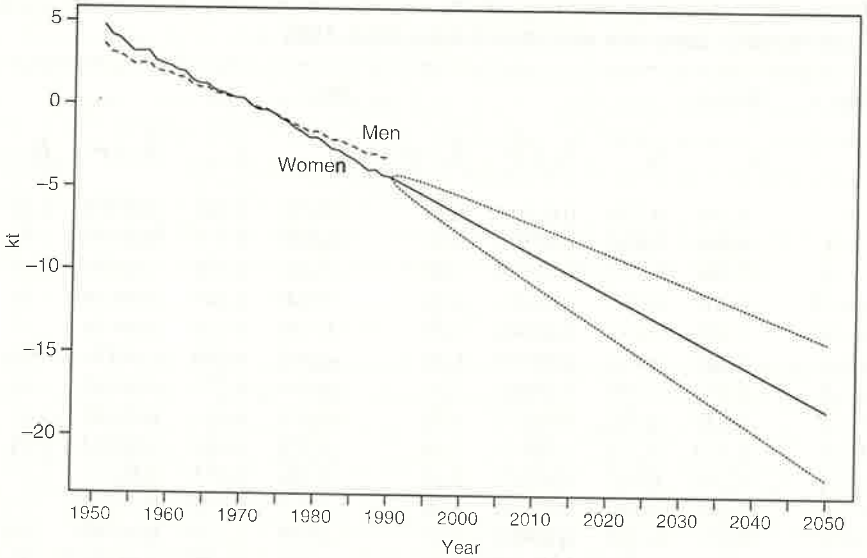

Fig. 13.1. Actual and projected Lee-Carter mortality index, k_t, with (approximate) 95-per-cent confidence intervals after 1990: Method I forecast, Japanese women and men, 1951–2050

Note: Projected k_t and confidence intervals are shown for women only.

those found through extrapolation. Visually, this forecasting procedure is well illustrated by Figure 13.2, which shows the observed trends in age-specific death rates above age 50 during 1951–90, along with projected values during 1991–2010. This graph illustrates the model's ability to capture differences in the pace of mortality decline in different age-groups.

Forecasts of age-specific mortality rates are easily translated into life expectancy at birth, as seen in Figure 13.3, which shows a best estimate based on linear extrapolation of the trend in k_t, along with 95-per-cent confidence intervals. According to these projections, life expectancy at birth would reach 89.0 years for women and 82.9 years for men in 2020, with 95-per-cent confidence bands of four to five years around those estimates. For purposes of this chapter, the procedure used to obtain this set of forecasts will be referred to as 'Method I'. For this and other methods, forecasts of Japanese life expectancy at birth up to 2050 are shown in Table 13.3.

Figure 13.4 presents another indicator of mortality change, namely, the proportion of the total population that may be classified as 'elderly'. In making these calculations, it is necessary to distinguish between the stationary and actual populations. Without considering the future of fertility in Japan, it is possible to forecast only the percentage of the stationary population that will be elderly in the future. As seen in Figure 13.4, this percentage will rise steadily according to the Method I forecast. The rise is substantially faster for

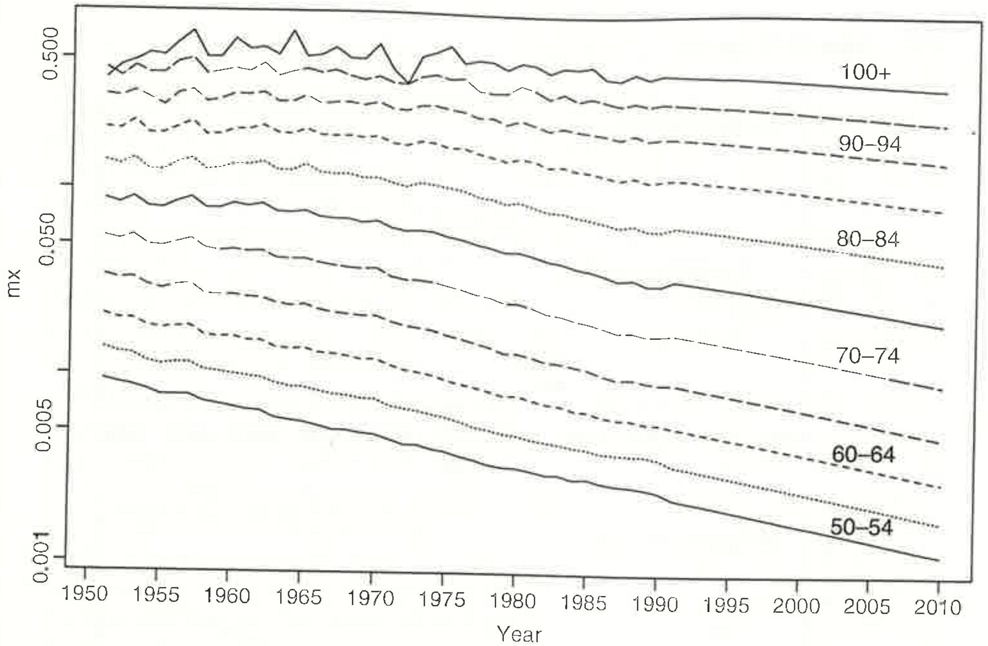

Fig. 13.2. Actual and projected age-specific death-rates: Method I forecast, Japanese women aged from 50–54 to 100+, 1951–2010

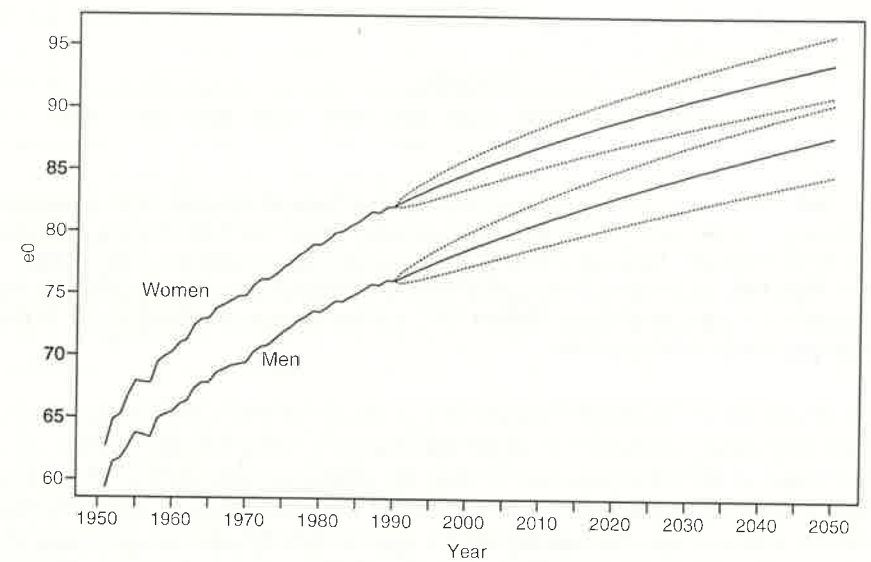

Fig. 13.3. Actual and projected life expectancy at birth e_0 with (approximate) 95-per-cent confidence intervals after 1990: Method I forecast, Japanese women and men, 1951–2050

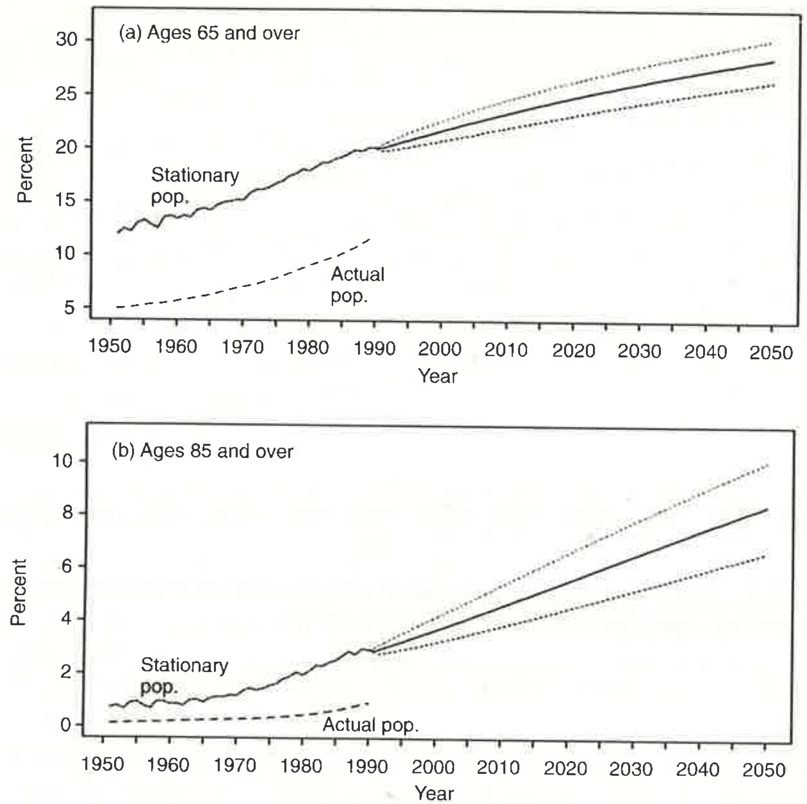

Fig. 13.4. Actual, stationary, and projected percentage of the population classified as 'elderly' (by two definitions) with (approximate) 95-per-cent confidence intervals after 1990: Method I forecast, Japanese women and men combined, 1951–2050
Note: After 1990 projections of the percentage of elderly people are only given for the stationary (life-table) population. Before 1990 the percentage of elderly people in the actual population is also shown.

ages 85 and above compared to ages 65 and above. In both cases, however, the actual population currently in these age-ranges is substantially smaller, as a percentage of the total population, than the stationary population. If fertility remains near the replacement level in Japan, the percentage of elderly in the actual population will rise steadily until it approaches the percentage of elderly in the stationary population. Thus, in terms of the actual population, there is the potential for continued dramatic growth in the percentage of the population that is elderly, if the forecasts of Method I are correct.

13.3. Method II: Total Mortality, Comparison with Swedish Trend

The most obvious criticism of the preceding forecast is that the pace of Japanese mortality decline over the past 40 years has been unusually rapid.

Although the Japanese now have the lowest mortality of any national population, in 1951 life expectancy at birth in Japan (approximately 63 years for women and 59 years for men) was well below the level enjoyed by most industrialized nations. A major portion of the Japanese mortality decline during this period, then, has been a matter of catching up with the traditional world leaders in this area, mainly Western Europe and North America. Now that Japan has moved ahead of these other nations (at least in terms of life expectancy), it is natural to ask whether it will be able to maintain its lead or even to move farther ahead of the pack.

It is instructive, therefore, to examine the history of Japanese mortality decline over a longer time-period than that considered in the previous section. Life-tables for the period 1891–1950 have been prepared by Nanjo and Kobayashi (1985) on the basis of eight period life-tables published previously. Yearly life-tables during this period were obtained by interpolation (and some limited extrapolation) of the earlier life-tables. Because they were constructed in this manner, the yearly life-tables for this period lack the detail and random fluctuations that can be observed in Japanese life-tables after 1950. There can be no doubt, furthermore, that the accuracy of the earlier life-tables is inferior to that of the later tables. Nonetheless, the life-tables for 1891–1950 can be added to those analysed previously to obtain a general picture of the pattern of Japanese mortality decline over a full century.

Estimates of k_t for the period 1891–1950 were obtained by a crude procedure that can be briefly described as follows: given the level of life expectancy for some year (taken from Nanjo and Kobayashi), a value of k_t was derived numerically that, when combined with the estimates of a_x and b_x in Table 13.1, reproduces the given e_0. This procedure contains the implicit assumption that the age-specific pattern of mortality change during 1891–1950 was close to the pattern during 1951–90. Although it is a simple matter to demonstrate the imprecision of this assumption, the procedure is convenient (e_0 is the only required data for 1891–1950) and seems adequate for the present purpose, which is merely to illustrate the irregular and unusual pattern of mortality decline that Japan has experienced over the past century.

Figure 13.5 plots the values of k_t that were obtained by this procedure for 1891–1950, along with those found previously for 1951–1990. The rather slow pace of mortality decline before 1945 contrasts sharply with the very rapid decrease after that date. This graph also presents estimated values of k_t for Sweden and France, whose patterns of mortality decline were much more regular.[4] Again, k_t for France and Sweden was estimated by matching on life expectancy using values of a_x and b_x derived for Japan during 1951–90. A more thorough analysis of the appropriateness of this procedure is recommended, although the general picture is likely to remain: the pattern of mortality

[4] Mortality data for France were supplied by Jacques Vallin (see Vallin, 1973). Life-tables for Sweden prior to 1960 are from NCBS (1969). For later years, life-tables are published annually by the National Central Bureau of Statistics (see references). Mortality rates for Sweden at advanced ages (above 80) were provided by Hans Lundstrom.

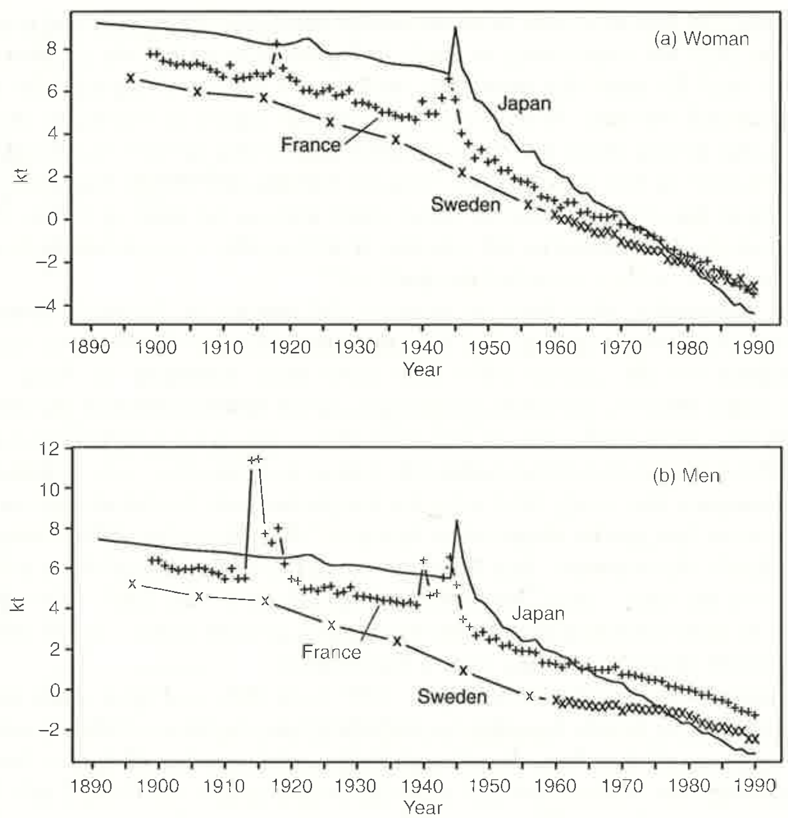

Fig. 13.5. Lee–Carter mortality index, k_t, for Japan, France, and Sweden, 1891–1990

decline, as measured by the variable $\hat{k}_t$, is more nearly linear for France and Sweden than for Japan. If the trends in estimated k_t for all three countries were extrapolated on the basis of the last 30–40 years of experience, the resulting forecasts of Japanese mortality would attain levels that are considerably below the levels projected for France and Sweden. In other words, Japan's lead in the race toward higher life expectancy would widen substantially.

A large increase in the mortality gap between Japan and other wealthy countries seems unlikely, however. The economic slowdown in Japan during the last few years, after four decades of astonishing growth, should be taken as evidence that Japanese society, having caught up with and even surpassed the other major industrial nations in numerous aspects of social and economic life, must now accept a slower pace of improvement in its quality of life. In terms of mortality decline, Japan's past accomplishments were made possible, in part, by the opportunity to imitate the world leaders in this area. Imported techniques of medicine and public health contributed to its steady and rapid

progress. Now, however, Japan is charting unknown territory. As it pushes back the limits of human mortality, Japan should probably expect that its rates of mortality decline will come to resemble those of the long-standing leaders in this field, such as Sweden and other countries of north-western Europe.

Ideally, we might attempt to forecast the trend in mortality of the world leader in this area (according to life expectancy at birth or some other measure) based on the experience of the past 100 years. For example, we might assemble a time-series of mortality rates to represent the experience of a fictitious country whose level of mortality at any point in the past was at least as low as in any other country at that moment in time. Extrapolating this trend into the future, we would project the minimum level of mortality that is likely to be achieved by any national population. Japan, and all countries for that matter, would then strive to attain this level in future years.

Although a time-series of this sort can be imagined, it cannot easily be constructed. Short of actually assembling the data required for this kind of analysis, though, we may conjecture that the mortality history of Sweden is not too far from this hypothetical level. Therefore, taking Sweden as a proxy for this hypothetical ideal national population, we can project Japanese mortality by forcing its future trend, again in terms of the variable k_t, to match the projected Swedish trend.[5] This procedure is called 'Method II'. Projected values of e_0 are shown in Figure 13.6 and Table 13.3. Tables 13.4 and 13.5 also give projections of life expectancy at age 65 and the percentage of elderly according to this method. It is important to note that in this forecast Japan retains its lead over Sweden, although that lead does not grow any larger, as suggested by Method I.

The difference in mortality forecasts according to Methods I and II is substantial after only a short period of time. By 2020 the projected values of e_0 differ by 3.2 years for women and 4.0 years for men. Differences in the projected percentage of the total population that will be elderly are also rather substantial. Furthermore, projected values of e_0 from Method II fall outside of the 95-per-cent confidence intervals shown earlier for Method I within 10 years or less. With regard to forecasting methodology, these results suggest that the structural assumptions used to derive a best estimate of future mortality levels may be considerably more important than the stochastic variability of the process itself. A further illustration of the importance of these structural assumptions emerges from an analysis of mortality patterns by cause of death, which is the topic of the next section.

[5] The Swedish trend in question was estimated on the basis of fitted k_t values for 1960–90 only. This choice was convenient since mortality data for single years of time in Sweden were available to the author only for these years. Arguably, this trend should be estimated based on a longer time-period. Especially for men, the procedure employed here may underestimate the current pace of mortality decline in Sweden.

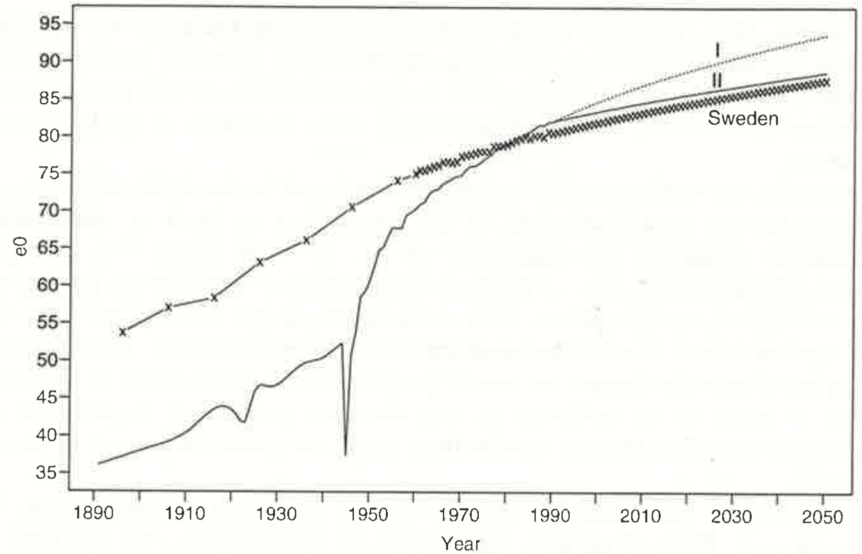

Fig. 13.6. Actual and projected life expectancy at birth, e_0: Method I and II forecasts, Japanese and Swedish women, 1891–2050

13.4. Methods III and IV: Cause-Specific Mortality, Baseline 1955–1990

Historical trends for total mortality demonstrate a high degree of regularity, as seen in the previous sections. With very few exceptions, mortality rates at every age and for both sexes have fallen steadily over the past century in Japan and in most other developed countries. Furthermore, the speed of this decline has remained nearly constant over long stretches of time. For mortality by cause of death, however, past patterns of change have not been so regular. Cause-specific death rates do not always show similar patterns of change at all ages, nor do they fall with the same temporal regularity as total mortality rates. For example, in Japan, death-rates due to cancer have been steady or falling slightly over the past three to four decades at adult ages less than about 70 years, but they have been rising over time at higher ages, most notably in the age-range above 85 years. Death-rates due to cerebrovascular diseases, on the other hand, showed little change during 1955–1970, but have fallen rapidly since then, accounting for a large portion of the increase in Japanese life expectancy during this period (Kono and Takahashi, 1985).

With these facts in mind, two alternative forecasting strategies present themselves. First, we could forecast total mortality as was done in the previous sections of this chapter, without regard to mortality trends by cause of death. Second, we could make separate forecasts by cause of death, then add up the individual cause-specific forecasts to obtain a forecast for total mortality. Various arguments could be put forth in support of one or the other strategy. Since death rates are falling for certain causes but are steady or increasing for others, the second strategy can be expected to yield more conservative forecasts of future gains in life expectancy. Arguably, these lower forecasts are more realistic given the fact that death-rates from certain causes, such as cancer at older ages, are not falling. Unless something happens to alter this historical pattern, progress against mortality at older ages will decelerate as total death-rates are composed increasingly of causes against which little or no progress is being made.

On the other hand, one might contend that progress against mortality has always been heterogeneous with respect to cause of death, or in other words, that humans have achieved higher and higher levels of life expectancy by attacking the various causes of death in succession. Kono and Takahashi (1985), for example, demonstrate that the increase in Japanese life expectancy during the three decades from 1950 to 1980 can be attributed to different causes of death in each time-period. During the 1950s, tuberculosis and gastroenteritis were the predominant causes behind the decline in total mortality. In the next decade, progress against pneumonia and bronchitis was the major contributor to increased life expectancy. From 1970 to 1980, the decline in mortality due to cerebrovascular diseases was the major component of the overall change. At the same time, it is worth noting that cerebrovascular disease was associated with very little change in total life expectancy during the 1950s, while tuberculosis and gastroenteritis had little impact on improvements in total mortality during the 1970s. The overall decline in death-rates was extremely regular over this period, as shown earlier in this chapter, but the major causes of death that contributed to these improvements changed dramatically.

In spite of these reservations, it may be useful to project mortality separately by cause of death and to compare the resulting forecast of total mortality with those obtained previously by simpler methods. Although mortality change is not as regular for all individual causes of death as for total mortality, the simple model described earlier is still useful for this purpose. In fact, for most causes of death, it describes a very high percentage of the total (weighted) variance in the data matrix of cause-specific mortality rates, as seen in Table 13.2. Most importantly, for the five largest categories in this breakdown (malignant neoplasms, heart diseases, cerebrovascular diseases, pneumonia and bronchitis, and other remaining causes of death), the model explains at least 99.4 per cent of the total variability in the data. For simplicity, then, it seems convenient and appropriate to use this same model as the means of forecasting all fifteen categories of causes of death.[6]

[6] The cause-of-death categories used here are those that were contained in the data generously provided to me by Shigemi Kono. Other breakdowns would be possible as well, but for now I have retained all available categories.

Table 13.2. Goodness-of-fit for Lee–Carter model by cause of death, 1955–1990, and distribution of deaths by cause in 1990. Japanese women and men

Cause of death[a]	Model Goodness-of-Fit		Percent of Deaths in 1990	
	Women	Men	Women	Men
1. Gastroenteritis	99.6	99.6	0.2	0.1
2. Tuberculosis	98.3	98.5	0.2	0.6
3. Malignant neoplasms	99.9	99.9	23.1	29.4
4. Diabetes	97.3	98.8	1.3	1.0
5. Heart disease	99.8	99.8	22.2	18.4
6. Hypertensive disease	99.0	99.4	1.6	0.8
7. Cerebrovascular disease	99.4	99.6	17.1	13.0
8. Pneumonia and bronchitis	99.6	99.5	8.6	9.5
9. Ulcer of stomach and duodenum	99.4	99.5	0.4	0.4
10. Chronic liver diseases and cirrhosis	99.5	96.7	1.4	2.6
11. Nephritis, nephrotic syndrome, and nephrosis	97.2	97.1	2.3	1.9
12. Senility without mention of psychosis	99.9	99.9	4.3	1.8
13. Accidents and adverse effects	99.1	97.8	2.6	5.0
14. Suicide	98.5	90.3	2.1	2.8
15. Other remaining causes of death	99.8	99.8	12.4	12.6
All Causes	99.9	99.9	100.0	100.0

[a] ICD-9 codes for the cause-of-death categories used here are as follows: 1. 008, 009, 535, 555, 556, 558, 562; 2. 010–018; 3. 140–208; 4. 250; 5. 393–8, 410–29; 6. 401–5; 7. 430–8; 8. 466.0, 480–6, 490–1; 9. 531–3; 10. 571; 11. 580–9; 12. 797; 13. E800–E949; 14. E950–E959; 15. all remaining ICD-9 codes.

The procedure for deriving projections of total mortality based on cause-specific mortality can be described briefly as follows:

1. the model in equation 1 was fitted to each matrix of cause-specific death rates for men and women separately over the period 1955–1990;
2. the trend in the estimated k_t for each cause of death was projected forward as a straight line whose slope was based either on the entire series or on a recent portion thereof, depending on the nature of the trend;[7]
3. projected cause-specific death rates were added together to yield forecasts of total mortality;
4. summary indicators of the mortality level, such as life expectancy or the percentage of elderly people in the stationary population, were calculated from the resulting total mortality rates. This forecasting procedure is referred to as 'Method III', and projections of life expectancy and the percentage of elderly people based on this method are presented in Tables 13.3, 13.4, and 13.5. According to this method, progress against mortality will be slower over the next few decades than projected by Methods I or II. For example, by 2020 projected life expectancy at birth is only 84.9 for women and 77.2 for men, compared with 89.0 and 82.9, respectively, according to Method I. Around 2025–30, moreover, the level of life expectancy anticipated by Method III begins to decline, since by that time old-age mortality will be composed almost entirely of causes, such as cancer, for which observed death-rates at these ages are currently increasing.

The observed pattern of change in cancer death-rates during 1955–90 deserves special consideration, since these trends are the driving force behind the eventual turnaround in levels of life expectancy projected (by Method III) to occur within about 40 years.[8] Figure 13.7 shows actual and projected cancer death-rates from 1955 to 2010. The projection method merely extrapolates past trends and has some validity only so long as these trends are an accurate representation of reality. It seems unusual, though probably not impossible, that observed cancer death-rates have increased markedly over time at ages 70 and above (and especially at ages 85 and above) while decreasing at younger ages. It seems less plausible, however, that the age pattern of cancer death-rates during the 1950s and 1960s could have been as depicted in this graph: rising until age 75, then falling off at higher ages. What possible explanation could account for this anomaly? Is it possible that changes in the method of reporting or coding causes of death have produced a spurious increase in cancer death-rates at older ages?

Given the possibility that observed trends in cause-specific death rates may be inaccurate, especially at older ages, it seems reasonable to propose one last projection method. 'Method IV' projects age-specific death-rates by cause, using the model in equation 1, but then adjusts the projected trends so that none of the age- and cause-specific death-rates increase over time. In other words, those trends that are decreasing at present are projected to continue on their current downward paths (exactly as in Method III), but those trends that are increasing are projected to remain constant at their current levels. With this assumption, it is of course impossible that projected life expectancy should begin to decrease at some point in the future, as observed for Method III.

[7] Projected trends were based on the entire observation period, 1955–90, for the following causes of death: 1, 2, 3, 8, 9, 10 (women only), 12, and 13. Some trends were projected based on the time-period 1975–90: 4, 5, 6, 7, and 14. A few causes of death were projected based only on trends during the most recent decade, 1980–90: 10 (men only), 11, and 15. (The names of the cause of death categories associated with these numbers can be found by referring to Table 13.2.) The choice of the time-period on which to base these projections was made by visual inspection of graphs of the variable k_t for the individual causes of death. (These graphs are available from the author upon request.) For those causes where the estimated k_t was visibly curvilinear, it was still possible to identify a nearly linear trend during some recent portion of the observation period. Quadratic or other forms for these extrapolations were avoided on the grounds that they tend to produce quite extreme projections after only a short time-period.

[8] Kobayashi *et al.* (1993) have noted that, unlike most developed countries, where heart disease is the number-one killer, cancer has been the leading cause of death in Japan since 1981.

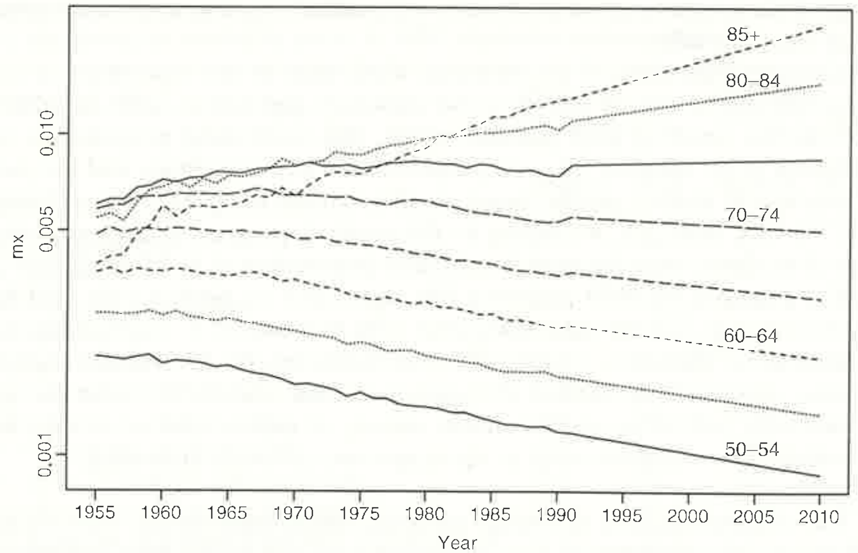

Fig. 13.7. Actual and projected age-specific cancer death-rates: Method III forecast, Japanese women, 1955–2010

Tables 13.3, 13.4, and 13.5 compare projected levels of life expectancy and the percentage of the elderly for Method IV with those from the first three projection methods. It can be seen that Method IV produces forecasts that are in between those of Methods I and III. From Tables 13.3 and 13.4 it is apparent that the projections of Methods II and IV are quite similar, especially for men. Both methods forecast life expectancies (at birth) in 2020 around 86 years for women and 79 years for men; by 2050, these levels would rise to about 89 and 81 years for men and women, respectively. According to projections II and IV, the pace of improvement in life expectancy can be expected to decelerate over this period, but it will not reach a fixed plateau or upper limit.

13.5. Discussion

Four forecasts of Japanese mortality have been presented based on various assumptions. Two of these methods employ what might be considered rather extreme assumptions: on the one hand, that total mortality in Japan will continue to decline with the same speed observed over the past 40 years (Method I); on the other hand, that observed trends in mortality rates by cause of death can be reliably extrapolated into the future (Method III). As seen earlier, these two methods produce vastly different forecasts of future

Table 13.3. Projected life expectancy at birth by four methods: Japanese women and men, 1990–2050

Year	Women				Men			
	I	II	III	IV	I	II	III	IV
1990[a]	82.1	82.1	82.1	82.1	76.1	76.1	76.1	76.1
1995	83.5	82.8	82.9	83.0	77.4	76.6	76.4	76.5
2000	84.8	83.5	83.6	84.0	78.6	77.1	76.8	77.2
2005	86.0	84.1	84.2	84.8	79.8	77.5	77.0	77.8
2010	87.0	84.7	84.5	85.5	80.8	78.0	77.2	78.3
2015	88.0	85.2	84.8	86.2	81.9	78.4	77.2	78.8
2020	89.0	85.8	84.9	86.7	82.9	78.9	77.2	79.2
2025	89.9	86.3	85.0	87.3	83.8	79.3	77.1	79.5
2030	90.7	86.8	84.9	87.8	84.7	79.7	76.9	79.8
2035	91.5	87.3	84.8	88.2	85.5	80.1	76.7	80.1
2040	92.3	87.8	84.7	88.6	86.4	80.5	76.5	80.3
2045	93.0	88.2	84.5	89.0	87.1	80.9	76.2	80.6
2050	93.7	88.7	84.2	89.3	87.9	81.3	75.9	80.0

[a] Observed value for 1990.

Table 13.4. Projected life expectancy at age 65 by four methods: Japanese women and men, 1990–2050

Year	Women				Men			
	I	II	III	IV	I	II	III	IV
1990[a]	20.2	20.2	20.2	20.2	16.4	16.4	16.4	16.4
1995	20.8	20.3	20.8	20.9	16.9	16.4	16.6	16.8
2000	21.6	20.7	21.2	21.6	17.6	16.7	16.7	17.2
2005	22.5	21.1	21.5	22.2	18.3	17.0	16.7	17.6
2010	23.3	21.6	21.7	22.7	19.0	17.2	16.7	17.9
2015	24.1	22.0	21.8	23.2	19.7	17.5	16.5	18.1
2020	24.9	22.4	21.8	23.6	20.4	17.8	16.3	18.3
2025	25.6	22.8	21.7	24.0	21.1	18.0	16.1	18.5
2030	26.3	23.1	21.5	24.2	21.8	18.3	15.8	18.7
2035	27.1	23.5	21.3	24.7	22.4	18.6	15.6	18.9
2040	27.7	23.9	21.0	25.0	23.0	18.8	15.3	19.0
2045	28.4	24.3	20.8	25.3	23.6	19.1	15.1	19.1
2050	29.0	24.6	20.4	25.6	24.2	19.3	14.9	19.3

[a] Observed value for 1990.

Table 13.5. Projected percentage of elderly people in the stationary population by four methods: Japanese total population, 1990–2050

Year	Ages 65 and over				Ages 85 and over			
	I	II	III	IV	I	II	III	IV
1990[a]	20.1	20.1	20.1	20.1	2.9	2.9	2.9	2.9
1995	20.9	20.3	20.6	20.7	3.2	3.0	3.2	3.3
2000	21.7	20.7	20.9	21.3	3.7	3.2	3.3	3.7
2005	22.6	21.1	21.2	21.8	4.1	3.4	3.3	4.0
2010	23.4	21.5	21.3	22.2	4.6	3.6	3.3	4.3
2015	24.2	21.8	21.3	22.6	5.1	3.7	3.2	4.6
2020	24.9	22.2	21.2	23.0	5.6	3.9	3.1	4.8
2025	25.6	22.5	21.1	23.3	6.0	4.1	2.9	5.0
2030	26.2	22.9	21.0	23.5	6.5	4.3	2.7	5.2
2035	26.9	23.2	20.8	23.8	7.0	4.5	2.4	5.4
2040	27.5	23.6	20.6	24.0	7.5	4.7	2.2	5.6
2045	28.0	23.9	20.4	24.2	8.0	5.0	1.9	5.8
2050	28.6	24.2	20.2	24.4	8.4	5.2	1.7	5.9

[a] Observed value for 1990.

mortality levels. Two other methods were proposed in an effort to attenuate the extreme nature of the assumptions in Methods I and III. Method II projects total mortality for Japan, but it forces the Japanese trend (in terms of the variable k_t) onto the more stable historical trend for Sweden. Method IV projects cause-specific mortality, but it rejects the notion that death-rates for certain ages and causes will continue to increase. The latter two methods produce very similar forecasts of future mortality levels.

The Institute of Population Problems within the Ministry of Health and Welfare has also prepared forecasts of Japanese life expectancy through 2025 (Institute of Population Problems, 1992). For women, these official forecasts are almost identical to the projections given by Method III and thus lie at the very low end of the range of forecasts for e_0 given in this chapter. For men, the official projections of future life expectancy are somewhat higher than those suggested by Method III but still lower than those resulting from Methods II or IV. It appears that the official forecasts underestimate (slightly) the gains in life expectancy that should be expected in Japan over the next 30–40 years. For both men and women, the difference is on the order of one year of life expectancy in the year 2020: official projections suggest life expectancies of around 78 and 85 years, while a best guess (based on Methods II and IV) is close to 79 and 86 years for men and women, respectively. Furthermore, the

official forecasts assume that mortality levels will stabilize in 2025, while the projections presented here (with the exception of Method III) suggest continued improvements even after this date.

Other forecasts of Japanese mortality levels have been published by Feeney (1990) and by the Longevity Study Group (1989) (citations for both works were taken from Kobayashi *et al.*, 1993). Feeney's projections of e_0 are considerably higher than even the most optimistic forecast (Method I): e_0 in 2000–4 would attain 81 and 88 years for men and women, respectively. The projections by the Longevity Study Group are much closer to the intermediate forecasts (Methods II and IV) than either Feeney's results or the official forecasts published by the Institute of Population Problems. In the short term, the forecasts by the Longevity Study Group are in between the intermediate and high-end forecasts, but by 2025 they are quite closely in agreement with the intermediate forecasts for both men and women proposed in this chapter.[9]

One final consideration concerns the age-pattern of mortality that is associated with each of the four projection methods discussed in this paper. Figure 13.8 compares the age-pattern of observed mortality in 1990 with the mortality curves for the various projections in 2020. The top curve in the graphs for both women and men shows the age-pattern of mortality in 1990. The bottom curve presents the age-pattern projected by Method I. The three curves in the middle of each graph correspond to Methods II, III, and IV.

At younger ages Methods III and IV yield almost identical mortality curves, especially for women; above age 70 or 80 the two curves diverge, with Method III projecting substantially higher death-rates in 2020,[10] especially for men. These similarities and differences are not surprising, since the two methods differ primarily in terms of their assumptions about observed increases in cause-specific trends, which have occurred mostly at older ages.

The projected curves associated with Methods II and IV are nearly identical above age 40, but they differ by a wide margin at younger ages. The differences below age 40 have a very minor impact on projected life expectancy, however, since death rates at those ages are already quite low. From a theoretical standpoint, the mortality levels projected by Method IV below age 40 are probably more realistic, since they acknowledge the fact that exogenous causes of death (mainly accidents, suicides, and homicides), which are the dominant causes of death at these ages, are unlikely to diminish substantially in the future.

[9] While I believe that Method I yields implausible forecasts in the long run, it seems somewhat more likely that the current pace of total mortality decline could continue for a few more years. Thus, the predictions of the Longevity Study Group are quite consistent with the analysis presented here.

[10] Note that the age-groups for Methods III and IV are different from the others (due to the age-groupings in the data that were provided to me for this project), in that they contain an open interval for ages 85 and over rather than for 100 and over.

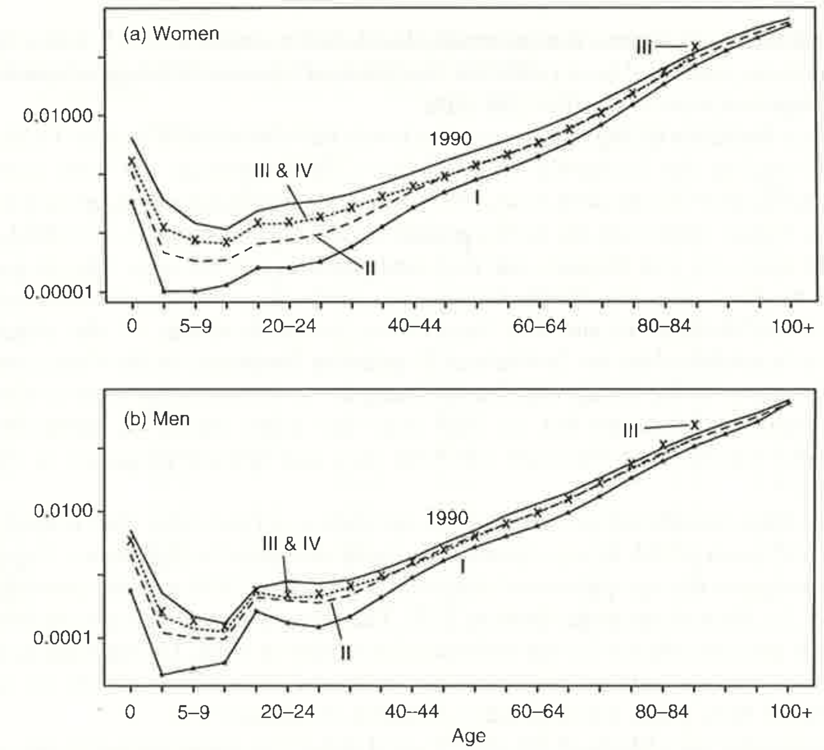

Fig. 13.8. Actual (1990) and projected (2020) age-patterns of mortality: Method I, II, III, and IV projections, Japanese women and men

13.6. Conclusion

A best guess based on the analysis in this chapter is that life expectancy at birth in Japan will rise gradually to about 79 years for men and 86 years for women by 2020. In this situation, a stationary population would have approximately 23 per cent of its members over age 65, and around 4 per cent above age 85. The actual percentage of the population at these ages also depends, of course, on future trends in fertility (Japan Aging Research Center, 1991).

It should be noted that these mortality projections are based entirely on extrapolations of observed empirical patterns and may need to be modified in light of biological theories of human ageing. In Japan, age-specific rates of (total) mortality decline have been nearly constant for about 40 years. From an international perspective, mortality decline among the leaders in this area, such as Sweden, has shown a remarkable degree of regularity for at least 100 years. Thus, while a large acceleration or deceleration of rates of mortality decline is certainly imaginable, any biological theory that predicts a major deviation from past trends should be firmly established and widely accepted by

the scientific community before it is embraced as a guide to public policy. In other words, theories that claim that the near future (say, the next 30–50 years) will be very different from the recent past (say, the last 100 years) must carry the burden of proof in the debate over the future of human mortality.

Regarding the methodology of empirical mortality forecasts, at least three notes of caution are in order. First, the technique of forecasting mortality separately by cause of death and then adding the results to obtain a forecast of total mortality is convenient but theoretically incorrect, since it does not account for the dependences that exist between various causes of death. At present, there do not appear to be any viable alternatives, given the inadequacy of our current theoretical and empirical knowledge of dependent competing risks. In this situation, the methods employed here may be instructive from an exploratory perspective, but the results that they yield must be interpreted with caution.

Second, the unusual pattern of mortality decline in Japan (rather modest improvements before World War II, followed by an exceptionally rapid decline thereafter) focuses attention on the need to consider the mortality history of one country in light of international trends. Japan's mortality history, which may be characterized as a transition from laggard to leader, is perhaps not the best base from which to derive empirical mortality forecasts for Japan itself. An alternative strategy developed in this paper (Method II) ties the forecast for Japan to the trend in mortality decline for a country that has been a long-time leader in this area, Sweden. This procedure could be refined by assembling a collection of period life-tables for a fictitious country that has possessed, at every moment in the past, the lowest level of mortality in the world. Such a time-series would lack most of the irregularities that complicate forecasts of the Japanese data. It would also provide a trajectory of mortality change to which all societies should aspire but which none could hope to surpass—unless, as some may suggest, the future is going to differ substantially from the past.

Lastly, the projections in this chapter demonstrate the wide range of forecasts associated with different models of mortality change. The analysis of forecast uncertainty by Lee and Carter (1992) focused on stochastic variation within a single model of mortality change. In this chapter, however, the confidence bounds within a single model (Method I) are somewhat smaller than the differences between the various models. Furthermore, the levels of mortality projected by the other models (Methods II, III, and IV) fall outside a 95-per-cent confidence interval for Method I within only a few years.

This chapter offers various scenarios of mortality change in Japan, each based on more or less plausible assumptions. The resulting forecasts may be thought of as high (Method III), medium (Methods II and IV), and low (Method I) scenarios, although it is important to keep in mind the assumptions associated with each scenario. It seems highly improbable that future trends will fall outside the range of forecasts offered here, since the high and low scenarios are each based on rather extreme and implausible assumptions. While demographers may be experts in making empirical forecasts like those presented here, we are only one among several groups of professionals who may wish to pass judgement on the plausibility of the assumptions that underlie those forecasts. For this reason, it is important that demographic forecasts be based on a range of possible assumptions and that those assumptions be stated clearly and discussed in detail.

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