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MORTALITY PATTERNS IN NATIONAL POPULATIONS

With special reference to recorded causes of death

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CHAPTER 5

Causes of Death and Age Patterns of Mortality

In this chapter and Chapter 6, attention is turned to the analysis of mortality structure rather than of mortality level. Age variation in mortality is the focus of the present chapter and sex of the next. Sex differentials have their own intrinsic interest because sex is one of the most fundamental biological and social distinctions. But age patterns are probably more important demographically because of the rapid evolution and application of techniques for estimating vital rates from census age distributions. These techniques rely upon the assumption that the age function of mortality in the population at hand is a member of one or another "families" of age functions, and the estimates are quite sensitive to the choice of family (United Nations, 1967). In particular, the estimated birth and death rates depend heavily upon whether the population is assumed to belong to a family having high or low mortality below age 10 relative to mortality above age 10. The basic purpose of this chapter is to identify some common sources of variation in age patterns of mortality and thereby to assist the user in choosing sensibly among the many available "families." However, the chapter begins with a brief description summary of the contribution of the causes of death to age-specific death rates and to changes therein.

Average Age Patterns of Mortality

The age pattern of mortality varies systematically with mortality level. This observation is commonplace and has been well documented in a variety of places (United Nations, 1955, 1963a; Coale and Demeny, 1966; Ledermann, 1969; Carrier and Hobcraft, 1971). In general, as mortality levels improve, the largest absolute declines in mortality occur at ages under 5 and above 65; the largest proportionate declines occur between ages 1 and 20. Assignment of these changes to causes of death is straightforward. The infectious diseases responsible for a large part of the mortality reduction have a U-shaped age pattern that is especially sharply angled for influenza/pneumonia/bronchitis, so that as these diseases are reduced to levels near zero, the age pattern of absolute reduction must also be U-shaped. The proportionate reductions, on the other hand, are largest in the older childhood ages where infectious diseases were the only major killers (i.e., where developmental conditions and degenerative diseases are not prominent).

Table 5.1 shows the average age pattern of mortality for all causes combined and for each individual cause of death in populations falling within five different ranges of life expectancy. The ranges are: 25–44.99 years; 45.00–54.99 years; 55.00–64.99 years; 65.00–69.99 years; and 70.00–74.99 years. The assignment of a particular population is based on the mean of male and female life expectancies; the sexes are not disassociated according to their respective levels because of interest in the comparative position of the two.

Figure 5.1 displays semilogarithmic graphs of the female age-specific death rates in quintiles of female life expectancy for certain of the causes or for combinations of causes. Quintile one refers to the 33 populations with lowest female life expectancy and quintile five to those with the highest. The figures reveal that the causes differ substantially in age pattern, with infectious and parasitic diseases being relatively flat after age 10, especially in high mortality populations, and tuberculosis relatively flat after age 20; influenza/pneumonia/bronchitis sharply U-shaped; the combination of diarrhea and certain diseases of infancy heavily concentrated below age 5; violence peaking locally in the early twenties, and rising again at older ages in a fashion that becomes steeper as mortality levels decline (the order of quintiles in terms of their average violence death rates at ages 5–9 is exactly reversed from their order at 80–84); maternal mortality shaped much like the age curve of fertility but with a tilt to the right; and all other causes being highly regular, virtually linear after age 30, and heavily concentrated at the older ages. The figures also indicate that age patterns of death by cause typically change as the level of mortality changes. If the death rates declined

Table 5.1

Average age-cause-specific death rates (per 1000) in populations grouped according to mean level of male and female life expectancy: populations with life expectancy below 45 years

Chile: 1909, 1920, 1930, 1940; Taiwan: 1920, 1930, 1936; Italy: 1881, 1891, 1901; England and Wales: 1861, 1871, 1891; South Africa (coloured): 1941; U.S. (nonwhite): 1920; Japan: 1908

Females

AGE	ALL CAUSES	RESP. T.B.	OTHER I AND P	CANCER	CARDIO-VASCULAR	INFL. PNUE. BRONCH.	DIAR-RHEAL	CERTAIN CHRONIC	MATER-NAL	CERTAIN DISEASES OF INF.	AUTO ACCIDENT	OTHER VIOLENCE	OTHER AND UNKNOWN
0	206.384	1.084	25.886	.067	3.360	41.724	29.971	.295	0.000	47.224	0.000	2.145	54.628
1	36.637*	.813*	9.392*	.040*	.495*	9.734*	6.360*	.257*	0.000	0.000	.005	.771	8.770*
5	6.869*	.453*	2.315*	.017	.238	1.408*	.437*	.097*	.000	0.000	.011	.267	1.626*
10	4.562*	.884*	1.192*	.021*	.286*	.866*	.149*	.065*	.014*	0.000	.004	.156	.925
15	7.238*	2.368*	1.155	.024	.404*	1.227*	.144*	.094*	.416*	0.000	.002	.293	1.111
20	9.611*	3.165*	1.185	.068*	.511*	1.629	.213*	.134	.928*	0.000	.005	.317	1.456*
25	10.542*	3.164*	1.169	.131*	.721*	1.887	.264*	.194*	1.113*	0.000	.005	.254	1.640*
30	11.339	3.015	1.104	.315*	.909*	1.988	.280*	.274	1.210*	0.000	.003	.241	2.300*
35	12.503	2.818	1.176	.563*	1.340*	2.122	.390*	.363	1.179*	0.000	.009	.242	2.301
40	13.247	2.545	1.167	.924*	1.855	2.355	.417	.434	.758*	0.000	.001	.265	2.526
45	15.161	2.454	1.179	1.384*	2.762*	2.769	.529	.599	.212*	0.000	.002	.272	2.999
50	18.575	2.348	1.347	1.833*	3.955	3.389	.672	.790	.028*	0.000	.006	.315	3.892
55	24.519	2.433	1.513	2.423*	5.761	4.431	.984	1.074	.010	0.000	.013	.353	5.574
60	35.783	2.491	1.735	2.730*	9.447	6.934	1.532	1.404	.006	0.000	.006	.502	8.996
65	52.517	2.719	2.208	3.350*	14.737	10.037	2.374	1.628	0.000	0.000	.072*	.556	14.636
70	74.491	2.940	2.590	4.123*	20.668	13.864	2.813	1.939	0.000	0.000	.002	.803	24.719
75	110.852	2.676	3.094	4.493*	30.728*	20.218	4.827	2.727	0.000	0.000	.073*	1.050	40.966
80	176.032	2.538	3.464	4.537*	39.523	26.799	9.155	3.336	0.000	0.000	.046	1.851	84.823
85	297.518	1.729	4.211	4.093*	53.866	41.358	15.613	4.350	0.000	0.000	0.000	2.757	169.541

Males

0	239.824	1.164	29.363	.086	3.872	49.087	33.397	.342	0.000	55.602	.002	2.470	64.439
1	35.613	.787	9.129	.035	.490	9.506	5.909	.240	0.000	0.000	.009	.855	8.653
5	6.527	.327	2.151	.017	.239	1.233	.407	.086	0.000	0.000	.016	.431	1.620
10	4.004	.420	1.017	.018	.249	.704	.147	.060	0.000	0.000	.010	.454	.925
15	6.648	1.657	1.172	.028	.369	1.215	.133	.086	0.000	0.000	.012	.860	1.116
20	9.581	2.712	1.441	.045	.454	1.786	.186	.135	0.000	0.000	.029	1.344	1.449
25	10.465	2.868	1.360	.062	.632	2.049	.225	.176	0.000	0.000	.025	1.421	1.647
30	11.734	3.027	1.470	.115	.893	2.387	.262	.274	0.000	0.000	.026	1.360	1.920
35	13.437	3.138	1.519	.228	1.308	2.759	.345	.386	0.000	0.000	.037	1.314	2.403
40	16.178	3.338	1.624	.477	1.921	3.455	.490	.562	0.000	0.000	.036	1.280	2.995
45	19.649	3.638	1.755	.761	2.755	4.164	.608	.788	0.000	0.000	.047	1.225	3.908
50	24.321	3.791	1.802	1.217	4.171	5.016	.833	1.042	0.000	0.000	.039	1.309	5.101
55	31.568	3.989	1.971	1.899	6.214	6.332	1.208	1.444	0.000	0.000	.037	1.333	7.141
60	43.377	4.118	2.305	2.464	9.655	8.830	1.754	1.698	0.000	0.000	.059	1.504	11.050
65	61.330	4.261	2.801	3.093	14.793	12.613	2.621	2.475	0.000	0.000	.049	1.500	17.174
70	84.242	4.134	3.169	3.815	20.742	16.336	3.274	2.969	0.000	0.000	.041	1.830	27.932
75	120.038	3.661	3.554	4.087	29.393	23.203	5.424	3.754	0.000	0.000	0.000	2.041	44.921
80	191.289	3.551	4.239	4.190	39.523	32.450	10.166	4.701	0.000	0.000	.026	2.659	89.784
85	320.989	2.145	4.751	3.880	54.633	51.014	16.933	6.401	0.000	0.000	.019	4.107	177.106

Table 5.1 (continued) Populations with life expectancy between 45.00 and 54.99 years

Chile: 1950, 1959; Colombia: 1960; Czechoslovakia: 1934; England and Wales: 1881, 1901, 1911; Guatemala: 1961, 1964; Italy: 1910, 1921, 1931; Japan: 1940; Portugal: 1930, 1940; South Africa (coloured): 1951, 1960; Spain: 1930, 1940; U. S.: 1900, 1910

Females

AGE	ALL CAUSES	RESP. T.B.	OTHER I AND P	CANCER	CARDIO-VASCULAR	INFL. PNUE. BRONCH.	DIAR-RHEAL	CERTAIN CHRONIC	MATER-NAL	CERTAIN DISEASES OF INF.	AUTO ACCIDENT	OTHER VIOLENCE	OTHER AND UNKNOWN
0	35.202	.044	1.513	.086	.167	5.298	3.025	.057	0.000	16.480	.020	.572	7.940
1	2.281	.020	.441*	.092	.036	.497*	.252	.032	0.000	.001	.056	.228	.626
5	.659	.010*	.123	.060	.036	.058	.017	.022	0.000*	.000	.058	.080	.169
10	.473	.018*	.064*	.049	.056	.034*	.006*	.029*	.001*	.000	.027	.063	.126
15	.730	.084*	.060	.064	.079	.035	.005	.038	.026*	.000	.050	.123	.166
20	1.019	.187*	.067	.084	.109	.039	.008*	.047	.096*	0.000	.044	.151	.187*
25	1.293	.244*	.068	.144	.156	.048*	.009*	.068	.140*	0.000	.033	.142	.241*
30	1.567	.243	.064	.263*	.238	.052	.011*	.093	.161*	0.000	.033	.146	.263
35	2.151	.245	.069	.514*	.388	.076	.013	.131	.160*	0.000	.035	.164	.356
40	2.923	.237	.076	.876*	.657	.103	.016*	.191	.088*	0.000	.037	.175	.467
45	4.322	.231	.082	1.453*	1.189	.153	.024*	.289	.014*	.000	.047	.218	.622
50	6.593	.242	.110	2.111	2.181	.239	.032*	.463	.001*	0.000	.054	.254	.966
55	9.792	.289	.146	2.845	3.806	.360	.040	.693	.001*	0.000	.061	.273	1.284
60	16.354	.380	.179	4.067	7.269	.687	.075	1.105	.001*	0.000	.092	.352	2.147
65	26.198	.437	.220	5.432	12.989	1.273	.131	1.680	.000	0.000	.093	.486	3.457
70	44.542	.531	.289	7.446	23.545	2.607	.239*	2.363	0.000	0.000	.127	.791	6.004
75	75.183	.579	.361	9.454	41.252	5.106	.428	3.208	.000	0.000	.165	1.534	13.096
80	125.078	.588	.410	11.462	66.793	9.573	.850*	3.845	.000	0.000	.166	3.044*	28.347
85	220.563	.488	.625	12.644	111.282	19.179	1.383	4.401	.000	0.000	.165	6.628*	63.768

Males

0	43.750	.060	1.673	.110	.205	6.208	3.534	.088	0.000	21.600	.044	.736	9.492
1	2.489	.023	.429	.114	.039	.488	.254	.039	0.000	.001	.093	.345	.664
5	.855	.009	.126	.078	.041	.063	.018	.024	0.000	.000	.104	.194	.198
10	.666	.011	.061	.068	.057	.031	.005	.022	0.000	.000	.069	.136	.146
15	1.245	.059	.073	.094	.093	.046	.005	.042	0.000	0.000	.204	.437	.195
20	1.846	.154	.070	.111	.113	.046	.007	.067	0.000	0.000	.329	.717	.226
25	1.924	.233	.070	.150	.167	.047	.008	.091	0.000	0.000	.252	.673	.233
30	2.199	.287	.074	.216	.280	.068	.009	.136	0.000	0.000	.204	.631	.294
35	2.939	.361	.095	.347	.566	.103	.013	.211	0.000	0.000	.191	.654	.398
40	4.253	.441	.113	.635	1.106	.164	.016	.314	0.000	0.000	.194	.714	.556
45	6.543	.554	.150	1.181	2.020	.273	.022	.504	0.000	0.000	.207	.808	.824
50	10.650	.754	.204	2.166	3.883	.489	.031	.761	0.000	0.000	.216	.918	1.229
55	16.738	.981	.268	3.726	6.686	.811	.052	1.092	0.000	0.000	.239	.950	1.933
60	27.005	1.230	.384	5.804	11.733	1.503	.098	1.602	0.000	0.000	.266	1.046	3.339
65	40.750	1.342	.415	8.257	19.148	2.445	.139	2.224	0.000	0.000	.315	1.098	5.367
70	62.791	1.425	.467	10.936	30.781	4.139	.238	2.965	0.000	0.000	.459	1.334	10.047
75	97.075	1.383	.521	13.688	49.084	7.226	.440	3.862	0.000	0.000	.499	1.846	18.526
80	151.069	1.329	.542	15.499	75.231	12.064	.834	4.780	0.000	0.000	.750	3.007	37.033
85	249.780	.965	.766	16.267	117.379	23.589	1.614	6.204	0.000	0.000	.855	5.395	76.746

Table 5.1 (continued) Populations with life expectancy between 55.00 and 64.99 years

Australia: 1911, 1921; Canada: 1921, 1931, 1941; Chile: 1964; Colombia: 1964; Costa Rica: 1960, 1964; Denmark: 1921, 1930; England and Wales: 1921, 1931, 1940; Ireland: 1951; Italy: 1910, 1920, 1930; Japan: 1951; Mexico: 1960, 1964; Netherlands: 1931; New Zealand: 1881, 1891, 1901, 1911, 1921, 1926; Panama: 1960; Portugal: 1960; South Africa (white): 1941; Sweden: 1911, 1920, 1930; Switzerland: 1930, 1941; Taiwan: 1960; U. S.: 1930, 1940; U. S. (white): 1920; U. S. (nonwhite): 1950; Venezuela: 1960

Females

AGE	ALL CAUSES	RESP. T.B.	OTHER I AND P	CANCER	CARDIO-VASCULAR	INFL. PNUE. BRONCH.	DIAR-RHEAL	CERTAIN CHRONIC	MATER-NAL	CERTAIN DISEASES OF INF.	AUTO ACCIDENT	OTHER VIOLENCE	OTHER AND UNKNOWN
0	135.149	.698	10.882	.073*	.766	24.526	35.503	.285	0.000	38.935	.002	.950	22.529
1	20.842	.444	5.192*	.052	.181	4.720	5.054*	.236	0.000	.109*	.014	.516	4.330
5	3.842	.194*	1.319*	.024	.164*	.533*	.344*	.088	0.000	.000	.018	.165	.973
10	2.438*	.386*	.626*	.024	.242*	.260*	.113*	.063*	.001*	0.000	.009	.106	.602
15	3.757	1.261*	.642	.041	.284*	.330	.097	.087*	.135*	0.000	.007	.172	.764
20	4.965	1.816*	.628	.064	.333*	.387	.120*	.127*	.415*	0.000	.011	.192	.872
25	5.494	1.825	.609	.130*	.427*	.446	.141*	.159	.541*	0.000	.012	.189	1.015*
30	6.146	1.630	.596	.281*	.629*	.549	.159*	.250	.635*	0.000	.024	.194	1.199
35	6.826	1.455	.572	.545*	.903	.637	.176*	.319	.636*	0.000	.027	.200	1.356
40	7.882	1.291	.558	.962*	1.369	.753	.213	.441	.410*	0.000	.010	.252	1.643
45	9.485	1.154	.589	1.463*	2.153	.919	.268	.627	.081*	0.000	.019	.268	1.974
50	12.701	1.123	.697	1.995*	3.430	1.334	.374	.853	.014*	0.000	.030	.274	2.577
55	17.649	1.065	.823	2.809*	5.296	2.074	.570	1.179	.003*	0.000	.036	.299	3.495
60	26.690	1.053	1.035	3.563	8.784	3.447	.887	1.605	.002*	0.000	.033	.397	5.084
65	41.192	1.153	1.268	4.720	14.810	5.436	1.429*	2.222	.004*	0.000	.027	.509	9.614
70	64.057	1.063	1.486	5.694	23.412	8.758	2.030	2.875	.000	0.000	.035	.790	17.914
75	97.758	1.100	1.712	6.785	35.436	12.923	3.032*	3.528	.001	0.000	.045	1.230	32.056
80	152.321	.829	2.407	6.752	46.904	19.578	4.387*	4.115	0.000	0.000	.019	2.047	65.283
85	247.219	.562	2.594	7.286	62.174	29.093	6.402	4.899	0.000	0.000	.041	3.365	130.803

Males

0	158.745	.789	11.690	.069	.959	28.642	40.290	.375	0.000	47.720	.011	1.011	27.189
1	21.060	.455	5.075	.059	.204	4.744	4.960	.262	0.000	.107	.025	.646	4.523
5	3.870	.160	1.251	.037	.158	.505	.311	.092	0.000	.000	.029	.324	1.003
10	2.420	.196	.575	.031	.199	.243	.107	.060	0.000	0.000	.024	.337	.648
15	3.932	.915	.645	.045	.270	.355	.102	.083	0.000	0.000	.044	.693	.780
20	5.637	1.807	.665	.069	.318	.437	.098	.118	0.000	0.000	.078	1.167	.880
25	6.252	1.941	.612	.095	.405	.498	.119	.176	0.000	0.000	.088	1.315	1.003
30	7.102	1.995	.649	.170	.614	.622	.136	.261	0.000	0.000	.107	1.303	1.245
35	8.247	2.045	.693	.281	.917	.829	.163	.382	0.000	0.000	.103	1.278	1.556
40	10.054	2.039	.798	.530	1.451	1.087	.221	.577	0.000	0.000	.107	1.268	1.977
45	12.963	2.187	.927	.954	2.314	1.428	.285	.825	0.000	0.000	.098	1.361	2.584
50	16.998	2.154	1.002	1.612	3.754	1.999	.388	1.206	0.000	0.000	.109	1.359	3.415
55	24.072	2.263	1.181	2.714	6.223	2.999	.591	1.696	0.000	0.000	.095	1.502	4.802
60	34.851	2.297	1.387	3.729	10.493	4.483	.932	2.338	0.000	0.000	.112	1.509	7.571
65	50.243	2.112	1.612	4.992	16.844	6.657	1.342	3.150	0.000	0.000	.113	1.536	11.885
70	76.805	1.857	1.955	6.369	26.290	10.573	2.035	4.083	0.000	0.000	.106	1.851	21.686
75	111.754	1.663	2.228	7.208	38.510	14.857	3.024	5.041	0.000	0.000	.148	2.225	36.850
80	166.856	1.359	2.847	7.315	50.083	21.632	4.297	5.622	0.000	0.000	.065	2.555	71.081
85	263.799	1.158	2.818	7.468	67.002	31.963	6.677	7.446	0.000	0.000	.173	3.844	135.250

Table 5.1 (continued) Populations with life expectancy between 65.00 and 69.99 years

Australia: 1933, 1940, 1951; Austria: 1961; Belgium: 1960; Canada: 1951; Denmark: 1940; England and Wales: 1951; Finland: 1951, 1960, 1964; France: 1951; West Germany: 1960, 1964; Hong Kong: 1961, 1964; Hungary: 1960, 1964; Ireland: 1961; Israel (Jewish): 1951; Italy: 1960; Japan: 1960; Malta and Gozo: 1964; Netherlands: 1940; New Zealand: 1936, 1945; Northern Ireland: 1960; Norway: 1946; Panama: 1964; Poland: 1960, 1964; Portugal: 1964; Puerto Rico: 1960, 1964; Scotland: 1951, 1960, 1964; South Africa (White): 1951, 1960; Spain: 1960; Sweden: 1940; Switzerland: 1951; Taiwan: 1964; Trinidad and Tobago: 1963; U.S.: 1960; U.S. (White): 1950; Venezuela: 1964; Yugoslavia: 1961, 1964.

Females

AGE	ALL CAUSES	RESP. T.B.	OTHER I AND P	CANCER	CARDIO-VASCULAR	INFL. PNUE. BRONCH.	DIAR-RHEAL	CERTAIN CHRONIC	MATER-NAL	CERTAIN DISEASES OF INF.	AUTO ACCIDENT	OTHER VIOLENCE	OTHER AND UNKNOWN
0	63.299	.190	5.191	.074	.298	11.098	9.747	.094	0.000	23.771	.011	.859	11.966
1	6.440	.089	1.851*	.063	.084	1.446	.915	.071	0.000	.000	.031	.424	1.466
5	1.850	.067	.638	.033	.118	.199	.078*	.054	0.000	0.000	.032	.128	.473
10	1.387	.181	.332	.035	.159*	.106*	.027	.070*	.004*	0.000	.015	.115	.343
15	2.276	.755	.333	.050	.200*	.145	.023	.083	.104*	0.000	.024	.162	.397
20	3.067	1.091*	.327	.076	.235*	.199	.031*	.114	.310*	0.000	.023	.179	.482
25	3.551	1.180*	.284	.138*	.306*	.244	.039*	.142	.447*	0.000	.018	.180	.573*
30	3.943	1.004*	.270	.288*	.442*	.315	.044	.200	.507*	0.000	.020	.179	.674*
35	4.745	.931	.275	.567*	.655*	.355	.064*	.292	.553*	0.000	.019	.195	.839*
40	5.476	.776	.290	1.022*	.976	.384	.060	.394	.298*	0.000	.024	.201	1.053
45	7.073	.705	.297	1.657*	1.621	.465	.080	.586	.06[illegible]	0.000	.028	.245	1.322
50	9.793	.671	.331	2.419*	2.675	.633	.121*	.882	.00[illegible]	0.000	.031	.257	1.770
55	13.875	.712	.432	3.249*	4.404	1.035	.153	1.334	.000	0.000	.046	.311	2.199
60	20.891	.728	.475	4.370	7.486	1.738	.245	1.918	0.000	0.000	.047	.386	3.498
65	31.782	.784	.526	5.890	12.499	3.009	.449*	2.590	.000	0.000	.055	.490	5.490
70	52.032	.792	.695	7.353	21.164	5.415	.724*	3.495	.001	0.000	.066	.852	11.475
75	83.127	.822	.926	8.970	32.746	9.302	.954*	4.514	0.000	0.000	.082	1.522	23.289
80	127.798	.737	.916	9.800	46.026	13.419	1.724*	5.262	0.000	0.000	.097	2.800	47.017
85	244.399	.409	1.503	12.758	76.827	25.399	2.896*	7.159	0.000	0.000	.064	6.053	111.331
							Males						
0	78.876	.197	5.677	.082	.444	13.520	11.888	.153	0.000	30.520	.011	1.024	15.360
1	6.850	.097	1.821	.074	.095	1.479	.947	.076	0.000	.000	.049	.609	1.603
5	2.112	.049	.653	.051	.120	.202	.077	.054	0.000	0.000	.063	.328	.515
10	1.548	.085	.333	.042	.137	.102	.029	.059	0.000	0.000	.041	.334	.386
15	2.504	.455	.347	.067	.183	.185	.027	.088	0.000	0.000	.085	.619	.448
20	3.636	.951	.346	.082	.214	.245	.027	.121	0.000	0.000	.127	.986	.537
25	3.862	1.051	.324	.113	.271	.269	.033	.166	0.000	0.000	.115	.969	.551
30	4.282	1.002	.325	.171	.380	.333	.044	.238	0.000	0.000	.104	1.029	.656
35	5.147	.991	.356	.317	.633	.443	.044	.365	0.000	0.000	.105	1.061	.832
40	6.529	1.016	.434	.574	1.067	.578	.066	.530	0.000	0.000	.115	1.074	1.075
45	8.898	1.069	.524	1.026	1.822	.774	.080	.832	0.000	0.000	.124	1.219	1.428
50	12.483	1.137	.608	1.872	3.174	1.042	.105	1.170	0.000	0.000	.130	1.252	1.993
55	18.200	1.265	.696	3.022	5.428	1.483	.180	1.679	0.000	0.000	.136	1.399	2.912
60	27.013	1.312	.749	4.790	9.087	2.209	.265	2.256	0.000	0.000	.162	1.502	4.681
65	40.642	1.334	.847	6.933	14.983	3.571	.356	3.206	0.000	0.000	.168	1.608	7.639
70	62.263	1.157	.830	8.945	24.095	5.714	.686	4.186	0.000	0.000	.181	1.783	14.686
75	95.750	1.085	.973	10.842	36.754	9.641	.922	5.567	0.000	0.000	.258	2.130	27.578
80	146.375	.871	1.035	10.856	51.024	15.030	1.497	6.959	0.000	0.000	.342	3.138	55.623
85	245.436	.642	1.295	11.626	73.765	26.399	2.702	8.598	0.000	0.000	.282	4.845	115.281

Table 5.1 (continued) Populations with life expectancy above 70 years

Australia: 1960, 1964; Austria: 1964; Belgium: 1964; Bulgaria: 1964; Canada: 1960, 1964; Czechoslovakia: 1960, 1964; Denmark: 1960, 1964; England and Wales: 1960, 1964; France: 1960, 1964; Greece: 1960, 1964; Iceland: 1964; Israel (Jewish): 1960, 1964; Italy: 1964; Japan: 1964; Netherlands: 1950, 1960, 1964; New Zealand: 1951, 1964; Northern Ireland: 1964; Norway: 1951, 1960, 1964; Sweden: 1951, 1960, 1964; Switzerland: 1960, 1964; U. S.: 1964

AGE	ALL CAUSES	RESP. T.B.	OTHER I AND P	CANCER	CARDIO-VASCULAR	INFL. PNUE. BRONCH.	DIAR-RHEAL	CERTAIN CHRONIC	MATER-NAL	CERTAIN DISEASES OF INF.	AUTO ACCIDENT	OTHER VIOLENCE	OTHER AND UNKNOWN
						Females							
0	20.808	.008	.509	.036	.101	2.323	.675	.026	0.000	11.011	.020	.484	5.555
1	1.053	.003	.104*	.111	.024	.153	.040	.011	0.000	.001	.089	.186	.331
5	.388	.001	.031	.072	.015*	.026*	.004	.010	0.000	.000	.073	.053	.103
10	.282	.003*	.015	.060	.028*	.014	.002	.013	.000	.000	.033	.038	.076
15	.433	.009*	.020	.064	.039	.013	.004*	.026	.007*	.000	.078	.079	.094
20	.586	.024*	.021	.087	.057	.014	.003	.036	.042*	0.000	.076	.114	.112
25	.698	.041*	.022*	.136	.091	.017	.005	.040	.058*	0.000	.042	.115	.131
30	.938	.060	.019	.264*	.138	.023	.005	.057	.058*	0.000	.040	.111	.163
35	1.380	.054	.029	.484*	.233	.027	.005	.077	.067*	0.000	.043	.142	.219
40	2.046	.060	.029	.839*	.419	.049	.010	.108	.031*	0.000	.053	.154	.294
45	3.300	.062	.041	1.411*	.813	.074	.010	.173	.005*	0.000	.060	.195	.456
50	4.929	.067	.054	2.039	1.496	.098	.020	.254	.001*	0.000	.080	.224	.596
55	7.809	.080	.064	2.936	2.791	.222	.027	.424	0.000	0.000	.086	.275	.904
60	12.673	.102	.089	3.974	5.529	.389	.045	.698	0.000	0.000	.116	.311	1.420
65	21.516	.140	.133	5.413	10.954	.783	.082	1.141	0.000	0.000	.132	.444	2.294
70	37.431	.199	.165	7.408	20.919	1.736	.165	1.763	0.000	0.000	.198	.812	4.066
75	65.605	.275	.228	10.023	39.010	3.797	.331	2.361	0.000	.000	.273	1.633	7.674
80	112.010	.317	.291	12.385	68.771	7.662	.557	2.950	0.000	0.000	.259	3.469*	15.349
85	208.114	.301	.415	15.184	122.175	17.411	1.054	3.525	0.000	0.000	.204	7.816*	40.029
						Males							
0	26.549	.008	.540	.109	.119	2.744	.781	.031	0.000	14.956	.022	.643	6.596
1	1.269	.004	.098	.129	.026	.154	.052	.011	0.000	.002	.118	.299	.376
5	.595	.001	.033	.100	.014	.023	.004	.010	0.000	.000	.119	.157	.134
10	.477	.001	.018	.087	.023	.015	.003	.014	0.000	.000	.073	.141	.102
15	1.016	.007	.022	.102	.059	.021	.002	.028	0.000	0.000	.307	.346	.131
20	1.378	.017	.021	.127	.079	.023	.004	.037	0.000	0.000	.419	.514	.146
25	1.353	.040	.019	.161	.122	.017	.005	.064	0.000	.000	.285	.478	.162
30	1.549	.070	.028	.216	.220	.024	.007	.089	0.000	0.000	.224	.482	.189
35	2.077	.096	.033	.345	.436	.044	.008	.135	0.000	0.000	.202	.517	.261
40	3.136	.116	.045	.602	.914	.079	.010	.199	0.000	0.000	.206	.568	.397
45	5.091	.162	.055	1.123	1.816	.129	.014	.330	0.000	0.000	.238	.650	.574
50	8.363	.216	.084	2.134	3.341	.250	.022	.496	0.000	0.000	.250	.701	.869
55	13.996	.304	.118	3.722	6.022	.518	.031	.758	0.000	0.000	.284	.828	1.411
60	22.533	.417	.157	5.975	10.361	.987	.048	1.137	0.000	0.000	.316	.838	2.297
65	35.450	.504	.233	8.781	17.385	1.817	.087	1.569	0.000	0.000	.400	.968	3.706
70	54.333	.618	.281	11.638	28.512	3.191	.148	2.137	0.000	0.000	.444	1.195	6.169
75	85.161	.670	.364	15.061	46.882	5.970	.273	2.810	0.000	0.000	.584	1.747	10.800
80	134.776	.616	.388	18.126	76.403	10.707	.592	3.434	0.000	0.000	.677	3.034	20.799
85	230.560	.611	.406	20.105	126.907	22.517	1.144	4.029	0.000	0.000	.672	6.207	47.962

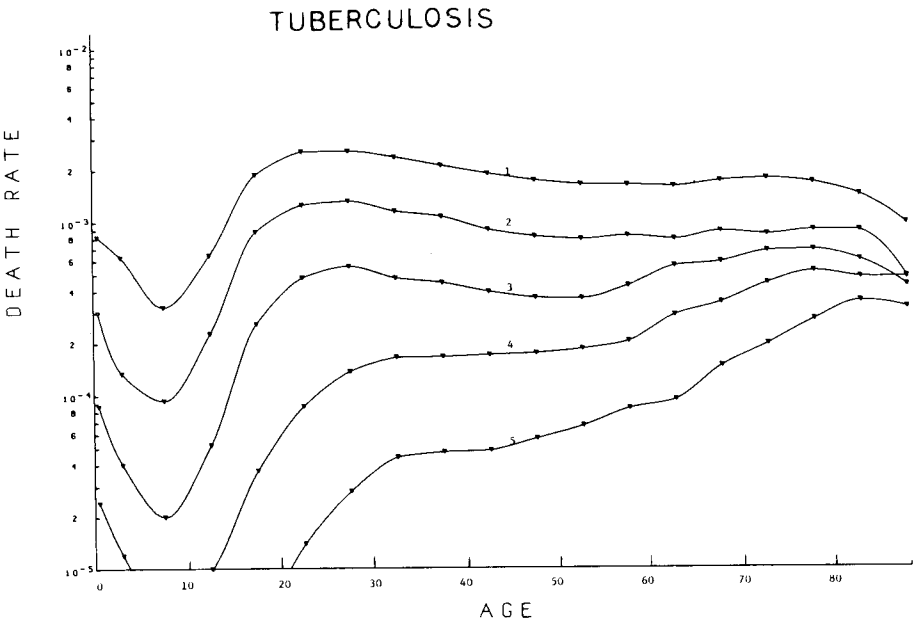
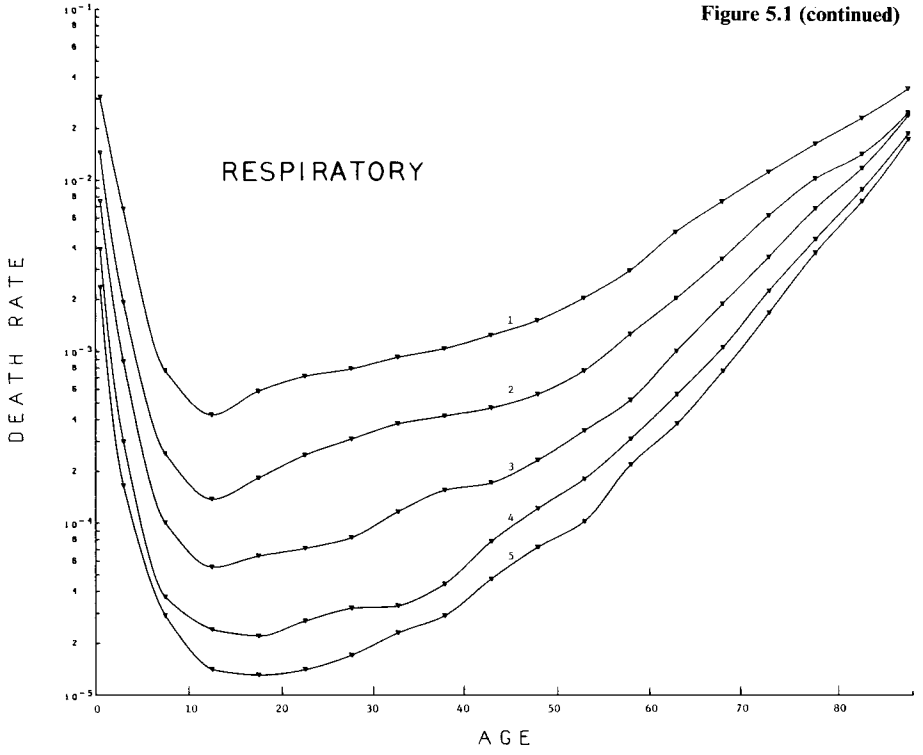


Figure 5.1 Female age curves of mortality from various causes in quintiles of life expectancy.

Figure 5.1 (continued)



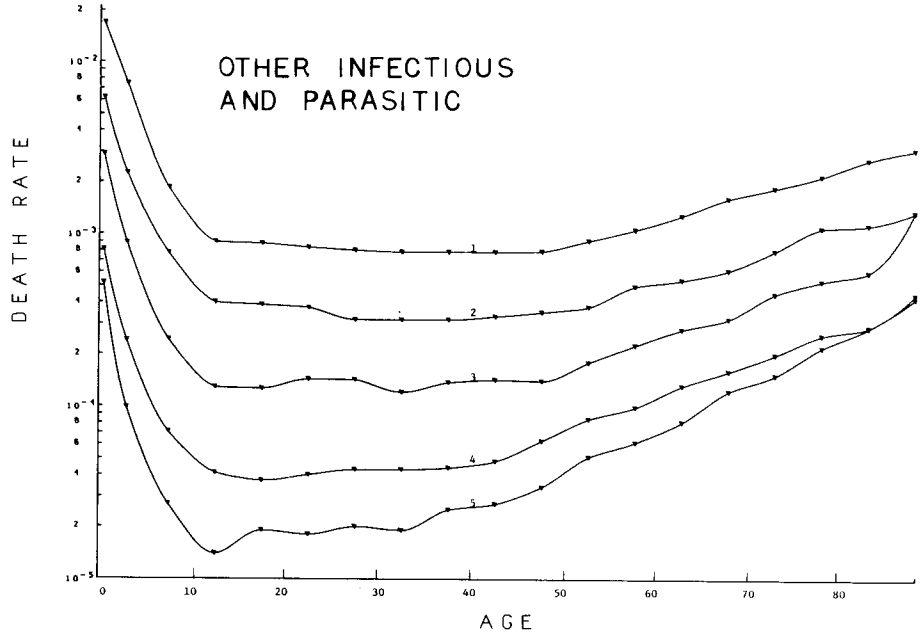
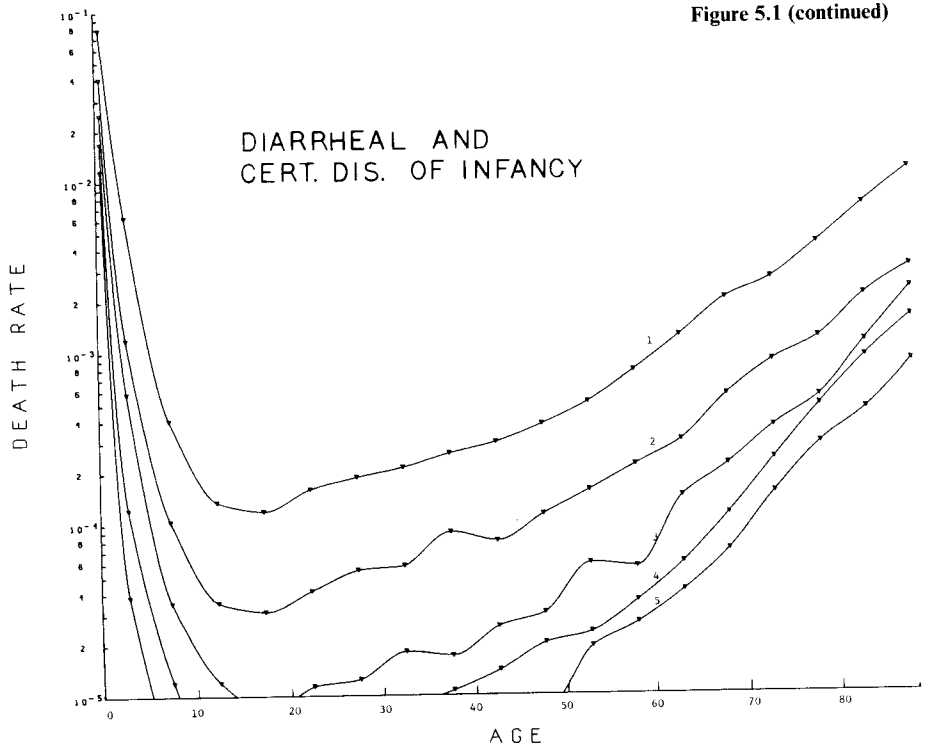
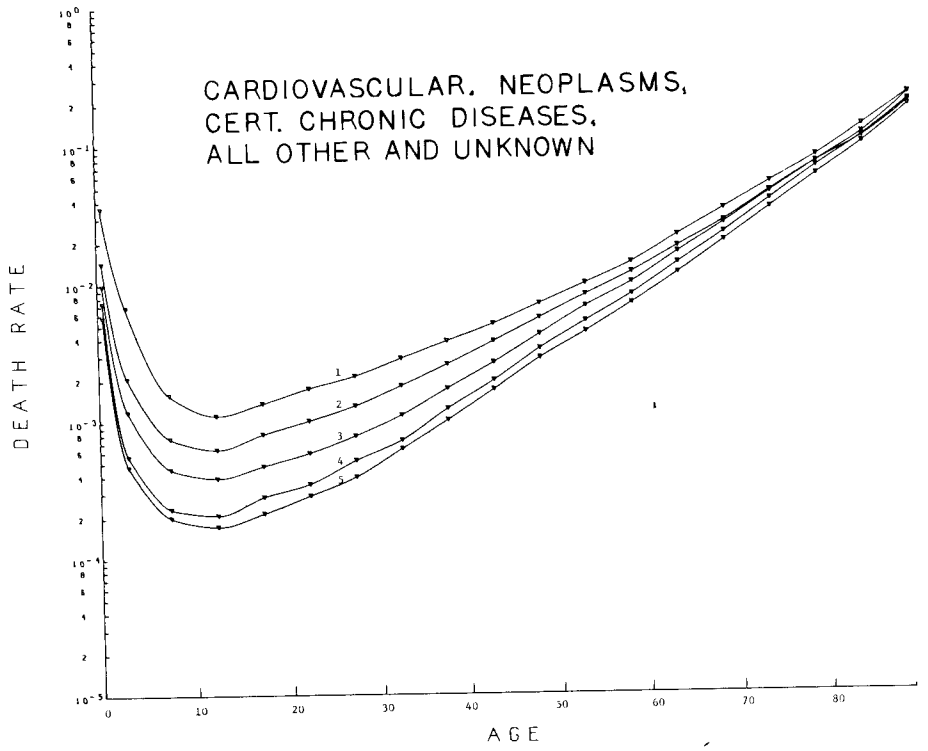


Figure 5.1 (continued)





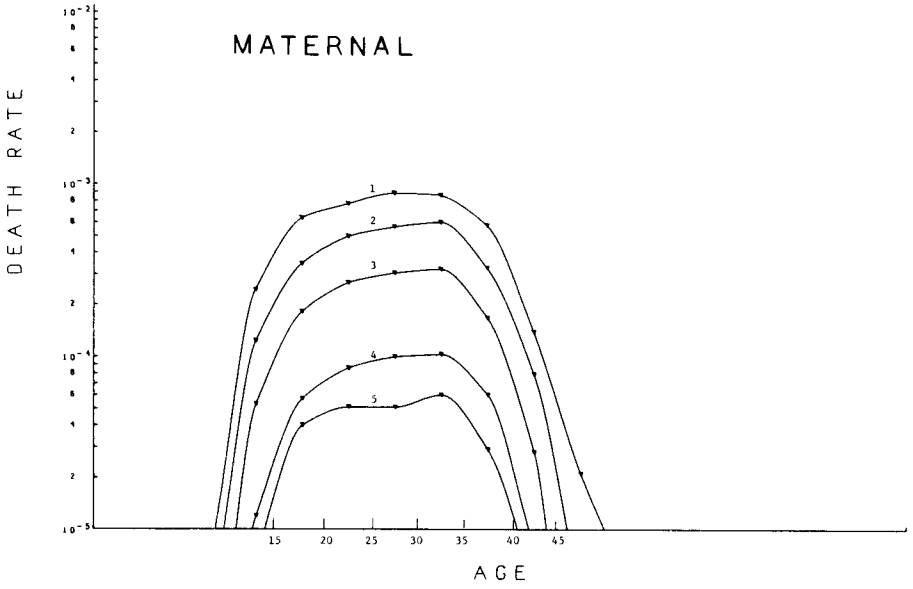
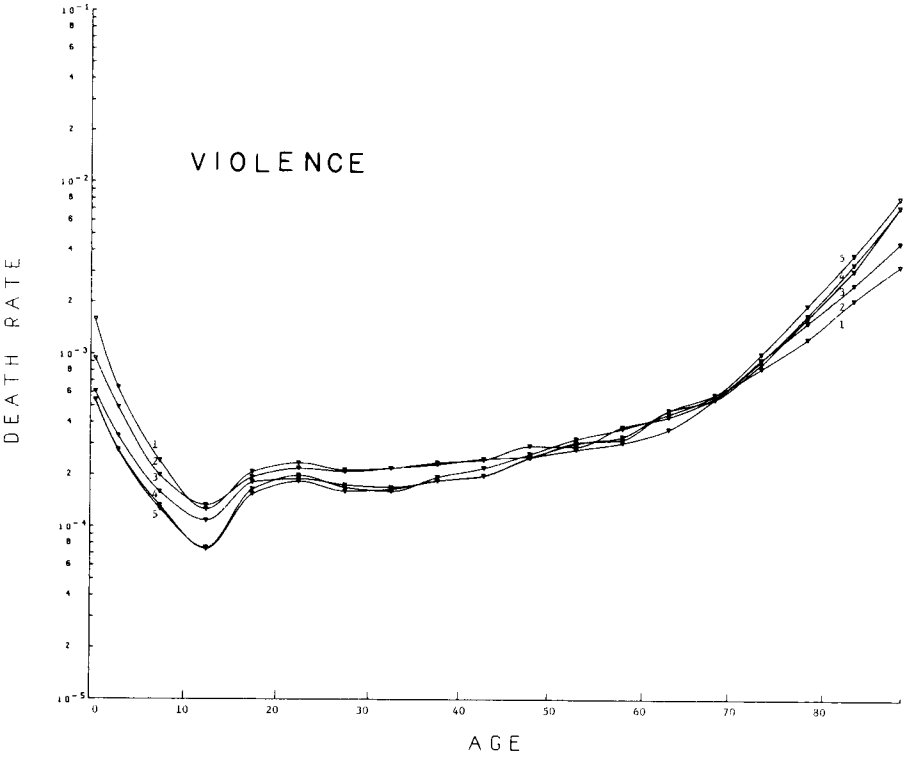


Figure 5.1 (continued)



by a factor constant with age, the age-curves would appear to be parallel on a semilog graph. But parallelism is not even a remote tendency except for "other infectious and parasitic diseases."

The cause of death making the largest contribution to declines in mortality at a particular age can be directly inferred by comparing populations at the lowest and highest levels of mortality in Table 5.1. A convenient index is

$$\text{Percentage contribution of cause } i \text{ to mortality decline at age } x = \frac{\text{(Average Death Rate, cause } i\text{, age } x \text{ in group 1 minus Average Death Rate, cause } i\text{, age } x\text{, in group 5)}}{\text{(Average Death Rate, all causes, age } x \text{ in group 1 minus Average Death Rate, all causes, age } x\text{, in group 5)}}$$

where group 1 are populations with average life expectancy less than 45 and group 2 are populations with average life expectancy above 70. Table 5.2 presents the two causes of death that are the largest contributors to mortality reduction at each age, exclusive of other and unknown causes whose contribution is difficult to interpret.

This table reveals the preeminent importance of influenza/pneumonia/bronchitis on an age-by-age basis. It is the first or second most influential cause for mortality reduction in every age interval except 10–19. Its contribution never falls below 17.8% of the total decline and reaches a peak of 36.3% at ages 75–79. The relative constancy of its contribution suggests that the age pattern of absolute decline in mortality from influenza/pneumonia/bronchitis is quite similar in form to that for all causes combined, though its angle is somewhat sharper.

Other causes that are influential at various ages are infectious and parasitic diseases at ages 1–19, respiratory tuberculosis at ages 10–49, cardiovascular disease at ages 50–59, and diarrheal disease at ages 75 and over. The importance of diarrheal and respiratory diseases at the extremes of life probably reflects both the great vulnerability of persons at these ages to chronic digestive and respiratory problems in populations with poor health levels and the tendency to assign deaths to symptomatic causes in such populations. Two causes of death with special social significance are moderately important causes of decline in certain age intervals. Maternal mortality is the third or fourth largest contributor to female declines at ages 25–39, accounting for between 10.0% and 11.1% of the total change, and "other violence" is the fourth leading source of male declines at ages 10–34, contributing between 8.6% and 10.3% of the total decline.

The leading cause of decline for males is identical to that for females at every age, and separate enumeration seems unnecessary. The list of second

Table 5.2

Causes of death making the largest contribution to declines in death rates by age for females

Age	Proportion of total decline when e_0^0 improves from <45 to >70 accounted for by				Proportion of total decline when e_0^0 improves from 45–54.99 to >70 accounted for by			
	Most important cause		Next most important cause		Most important cause		Next most important cause	
0	Influ./pneu./bronch.	(.212)	Cert. dis. inf.	(.195)	Diarrheal	(.304)	Cert. dis. inf.	(.244)
1–4		(.269)	Infec. & para.	(.261)	Infec. & para.	(.257)	Diarrheal	(.253)
5–9	Infec. & para.	(.352)	Influ./pneu./bronch.	(.213)		(.373)	Influ./pneu./bronch.	(.147)
10–14		(.275)	Resp. T.B.	(.206)		(.284)	Resp. T.B.	(.178)
15–19	Resp. T.B.	(.346)	Infec. & para.	(.166)	Resp. T.B.	(.376)	Infec. & para.	(.187)
20–24		(.348)	Influ./pneu./bronch.	(.179)		(.409)		(.138)
25–29		(.317)		(.190)		(.372)		(.122)
30–34		(.284)		(.189)		(.301)		(.111)
35–39		(.248)		(.188)		(.257)	Cardiovascular	(.125)
40–44		(.222)		(.206)		(.211)		(.163)
45–49	Influ./pneu./bronch.	(.227)	Resp. T.B.	(.202)	Cardiovascular	(.216)	Resp. T.B.	(.176)
50–54		(.241)	Cardiovascular	(.180)		(.248)	Influ./pneu./bronch.	(.158)
55–59		(.252)		(.178)		(.254)		(.188)
60–64		(.283)		(.169)		(.232)		(.218)
65–69		(.298)		(.122)	Influ./pneu./bronch.	(.236)	Cardiovascular	(.195)
70–74		(.327)	Resp. T.B.	(.074)		(.264)		(.093)
75–79		(.363)	Diarrheal	(.099)		(.284)	Diarrheal	(.084)
80–84		(.299)		(.134)		(.296)		(.095)
85+		(.267)		(.162)		(.299)		(.137)

most important contributors is also identical except that for males influenza/pneumonia/bronchitis appear at ages 10–19, and respiratory tuberculosis at ages 50–69.

The list of important causes does change substantially, however, when declines are measured from the next higher level of life expectancy. The two rightmost columns in Table 5.2 identify the causes most influential in mortality declines when mortality improves from a life expectancy in the range of 45.–54.99 to one of above 70. In general, the importance of influenza/pneumonia/bronchitis declines. Its appearance as the leading cause of mortality decline is now confined to ages over 65, and there it typically makes a smaller percentage contribution than before. These results are congruent with the indication in Chapter 2 that the relation between age-standardized death rates from this cause and from all causes combined is nonlinear. Causes that emerge as more important in the truncated mortality transition are diarrheal diseases at ages 0–4 and cardiovascular diseases at ages 45–64, where there are now the leading source of mortality change. Indications from Chapter 2 are that they would also emerge as influential at higher ages if the disturbing role of "other and unknown" could be effectively eliminated. In general, the figures presented in Table 5.2 are probably all seriously affected by the presence of deaths to which no precise cause has been assigned, and the values must be considered suggestive rather than definitive.

Variations in Age Patterns of Mortality

Not all populations falling into a certain mortality range have age patterns similar to the average for that range, even when the range is very narrow. The considerable variability is a source of much uncertainty when estimating vital rates from age distributions. The variability cannot be attributed to random error. For example, Coale and Demeny (1966) have identified four distinct and persistent regional age patterns of mortality in Europe, and Brass (1968) has identified a distinctive tropical African pattern. The purpose of the remainder of this chapter is to show that much of the variability in age patterns of mortality for populations at the same mortality level can be ascribed to differences in their underlying cause-of-death structure.

The question with which it is concerned can be rephrased in the following way: "How much more accurately can age curves of mortality be predicted on the basis of rates of death rates from various causes than on the basis of death rates from all causes combined?" Causes of death rates would offer no additional information if age curves of mortality from the various causes were identical in shape, varying only in level, or if the level of mortality

from each cause were perfectly correlated with the level of mortality from every other cause. (These conditions will be made more precise momentarily.) The values in Table 5.1 indicate clearly that age patterns vary among the causes. Table 2.3 showed that, while death rates from many causes are highly correlated with one another, the correlation is far from perfect, and is nearly zero for some combinations. Taken together, these tables suggest the value of introducing information on cause.

In order to measure the added predictive value of cause of death structure, it is first necessary to see how well age patterns can be predicted in the absence of such information. Here we will adopt the purely empirical, atheoretical approach pursued by previous authors and attempt to construct an empirical model of age patterns. The original United Nations (1955) model mortality patterns used second-degree polynomial regressions to summarize the relationship between death rates in adjacent age intervals, but the contribution of the second-degree term was typically quite small. In their reformulation of the U.N. models, Gabriel and Ronen (1958) ignored the second-degree term altogether, and Ledermann's (1969) later revision assumed linearity except for those relationships involving ${}_4q_1$, the probability of dying between ages 1 and 5. Even here the nonlinearity is virtually invisible to the naked eye (Ledermann, 1969, p. 20).

If the death rate at each age is linearly related to the death rate at every other age, then it is linearly related to a linear combination of death rates at all ages. We will measure mortality "level" by such a linear combination of age-specific death rates, in particular by an age-standardized crude death rate:

$$\text{ASCDR} = \sum_i c_i^s \cdot M_i,$$

where c_i^s is the proportion of the standard population in the ith age interval and M_i the death rate in the ith age interval. Any linear combination in principle will do; in practice we choose the one introduced in Chapter 2. Note that the expectation of life is *not* a linear combination of age-specific death rates. Instead, the ${e_0}^0$ implicitly assigns to death rates at the several ages weights which vary from population to population, depending on the mortality function itself. Since mortality rises with age over most of its range, a reduction in mortality produces more survivors to ages of higher mortality and thus is partially offset in its effect on life expectancy.[1] As a result, the relation between death rates at a particular age and *life expectancy* is curvilinear, as noted empirically by Ledermann (1969: Section 2–10).

[1] This proposition is formally demonstrated for the linear case in Preston (1972, p. 207).

We can therefore expect the relationship between death rates at a particular age and overall mortality level to be satisfactorily represented by a linear function on the age-standardized crude death rate. Linear correlation and regression is a convenient means of deriving the coefficients of the relationships and measuring their goodness-of-fit. Examination of residuals from the regressions indicates that the error assumptions of classical least squares regression are not severely violated in our data.

Before proceeding to the calculations, we modify the dependent variable slightly by first noting that the probability of survival between age x and age $x + n$, ${}_nP_x$, can be written as

$$ {}_nP_x = \exp\left(-\int_x^{x+n} \mu_t \, dt \right), $$

where μ_t is the annual death rate at exact age t. Thus,

$$ -\log {}_nP_x = \int_x^{x+n} \mu_t \, dt. $$

Since mortality at all ages is assumed to be a linear function of the age-standardized crude death rate, and since the natural logarithm of the probability of survival is simply a sum of age-specific death rates, the logarithm should also be a linear function of the age-standardized crude death rate:

$$ \log {}_nP_x = {}_nA_x + {}_nB_x \cdot \text{ASCDR}. \tag{5.1} $$

Equation 5.1 provides a convenient means of relating the index of mortality ASCDR to life table parameters and will be utilized throughout this chapter.

Coefficients of the relationships between $\log {}_nP_x$ in various age intervals and the age-standardized crude death rate are displayed in Table 5.3. These coefficients are calculated by classical least squares methods applied to 163 observations.[2] For convenience, we deal throughout with six age intervals. It should be noted that the values of mortality parameters for one of these age intervals are based upon mortality rates in intervals of 5 years or less. Regardless of the width of the interval displayed, the estimated parameters for an interval are not subject to age distributional disturbances.

The model of mortality relationships contained in Table 5.3 is very similar to that of the United Nations' model life tables and that of the Coale–Demeny "West" pattern. Both of these represent "average" patterns, the former based upon all populations examined and the latter upon all populations remaining after anomalous cases had been removed. Table 5.4 com-

[2] Chile (1909) and Taiwan (1920) were excluded from the analysis in the remainder of this chapter because of serious questions about the accuracy of their age reporting. Hence the number of populations in the data set declines from 165 to 163.

Table 5.3

Regression equations relating life table functions to level of mortality:

$\log(l_{x+n}/l_x) = a_x + b_x \cdot \text{ASCDR} + \epsilon$

Dependent variable	a_x	b_x	R^2	Cause of death having highest partial correlation with $\log(l_{x+n}/l_x)$ holding constant ASCDR	
FEMALES					
$\log(l_1/l_0)$	.05356	−9.8722 (.2947)	.874	Cert. dis. of infancy	(−.606)
$\log(l_5/l_1)$	.05977	−7.7134 (.2243)	.880	Diarrheal diseases	(−.582)
$\log(l_{20}/l_5)$	.02982	−4.5684 (.1162)	.906	Infec. and para.	(−.499)
$\log(l_{40}/l_{20})$	.05411	−9.9101 (.2642)	.897	Tuberculosis	(−.661)
$\log(l_{60}/l_{40})$	.00036	−13.5567 (.4520)	.848	Cert. chronic dis.	(−.506)
$\log(l_{80}/l_{60})$	−.44342	−40.0032 (1.2358)	.867	Cardiovascular	(−.434)
MALES					
$\log(l_1/l_0)$	.09451	−11.5953 (.3482)	.872	Cert. dis. of infancy	(−.609)
$\log(l_5/l_1)$	.07836	−7.5193 (.2717)	.826	Infec. and para.	(−.624)
$\log(l_{20}/l_5)$	.03007	−3.8824 (.1467)	.814	Infec. and para.	(−.694)
$\log(l_{40}/l_{20})$	.06562	−9.5712 (.3104)	.856	Tuberculosis	(−.475)
$\log(l_{60}/l_{40})$	.00675	−15.8733 (.4794)	.872	Violence	(−.422)
$\log(l_{80}/l_{60})$	−.67160	−34.2633 (1.8687)	.676	Cardiovascular	(−.610)

pares the female survivorship columns of the three models at four different levels of mortality. The three models are in close correspondence, especially when contrasted with other regional families. They are virtually identical at the lowest level of mortality. At the next lowest level, the present model's survivorship column is always intermediate between the other two, even though they themselves cross. At higher levels, a slight tendency emerges for the present pattern to display lower death rates at older ages, and the U.N. pattern slightly higher rates at those ages. In short, the equations of Table 5.3 produce models of mortality relationships quite similar to those

of two other "average" patterns, despite differences in the sample of populations and in the specification of the relationships. We can be confident that neither our sample nor our specification substantially misrepresents average mortality relationships.

Table 5.3 also shows that 80–90% of the variance in the death rate at a particular age could be "explained" by variation in the death rate at all ages combined. For some purposes, this is an acceptable degree of predictability. For use in inferring vital rates from census data, however, one seeks greater accuracy. Even relatively minor variations among model age curves of mortality can produce major differences in estimates of demographic parameters. Their sensitivity results in large part from the fact that, in census age distributions, a recent infant death is indistinguishable from a birth that never occurred. For example, United Nations Manual IV (1967, p. 42) shows that stable estimates of birth rate in a hypothetical population vary from 44.5 to 50.1/1000, depending upon whether the "West" or "South" model mortality patterns are used.

How much of the unexplained variance in age specific death rates is caused by differences in the cause-structure of mortality at a particular level? Table 5.3 permits some initial observations on this point. Partial correlation coefficients between $\log {}_nP_x$ and age-standardized death rates *from particular causes* ($ASCDR_i$) are displayed, with ASCDR held constant. The causes of death that are most closely associated with age-specific death rates for both sexes are, starting at the lowest ages: certain diseases of early infancy; infectious and parasitic diseases; tuberculosis; and cardiovascular disease. It is clear that a disease proves to be significant at an age where one expects its relative incidence to be greatest. This result offers the first indication of the importance of cause of death structure for age curves of mortality.

Variation in Model Age Patterns Attributed to Varying Causes of Death Structures

In order to introduce causes of death into model age patterns of mortality, we require information on the manner in which age-specific death rates *from a particular cause* are related to one another among populations. In this matter there are no previous studies available for reference, and we must rely upon the cause of death data forming the basis of this study. Unfortunately, there are 3672 individual relationships between cause-specific death rates at two different ages to be examined, with 163 observations on each. As a result, it was necessary to draw samples both from the

Table 5.4

Proportions surviving from birth to age x in various model female life tables at four levels of mortality[a]

Age (x)	Coale–Demeny "West", $e_0^0 = 72.5$	Computed from Table 5.3 ASCDR = .00806	U.N., $e_0^0 = 73.09$	Coale–Demeny "West", $e_0^0 = 60.0$	Computed from Table 5.3 ASCDR = .0133	U.N., $e_0^0 = 60.17$
0	1.000	1.000	1.000	1.000	1.000	1.000
1	.977	.974	.978	.929	.926	.918
5	.973	.972	.973	.899	.886	.886
20	.966	.966	.965	.870	.860	.858
40	.943	.941	.939	.800	.795	.793
60	.849	.844	.846	.656	.664	.669
80	.392	.392	.399	.230	.250	.253

Age (x)	Coale–Demeny "West", $e_0^0 = 47.5$	Computed from Table 5.3 ASCDR = .0205	U.N., $e_0^0 = 47.63$	Coale–Demeny "West", $e_0^0 = 35.0$	Computed from Table 5.3 ASCDR = .0300	U.N., $e_0^0 = 34.31$
0	1.000	1.000	1.000	1.000	1.000	1.000
1	.868	.862	.860	.786	.784	.791
5	.797	.781	.795	.672	.661	.681
20	.743	.733	.743	.597	.594	.601
40	.634	.631	.635	.459	.465	.449
60	.469	.478	.478	.292	.310	.274
80	.125	.135	.131	.050	.060	.046

[a] A. Coale and P. Demeny (1966, pp. 8, 13, 18, 23); United Nations Department of Social Affairs (1955, Table I).

total number of possible relationships and from the number of observations available on each. In the process of plotting these relationships, it quickly became apparent that linearity continued to be a good approximation of the shape of these relationships. For several causes of death, most notably other infectious and parasitic diseases, the constant terms were typically quite close to zero.

It follows as before that if death rates from a particular cause at various ages are linearly related to one another, then they are each linearly related to a linear combination of such rates. Since the death rate from all causes combined is a summation of death rates from the individual causes, it is a summation of such linear combinations:

$$\log {}_np_x = A'_x + \sum B_x{}^i \cdot \mathrm{ASCDR}^i, \tag{5.2}$$

where

$$A'_x = \sum_i A_x{}^i$$

is the sum of constants in the cause-specific regression. Equation 5.2 is the form in which model patterns that incorporate information on causes of death will be developed. Equation 5.2 must explain variance in $\log {}_np_x$ at least as well as Equation 5.1. It would do no better if

(a) The $B_x{}^i$'s were always equal for the different causes; in effect, if the age curve of mortality variation were the same from cause to cause. The age curves themselves could differ radically as long as the difference did not vary with mortality level but was contained exclusively within the $A_x{}^i$ terms. Or if

(b) Causes of death were always found in linear combination with one another, in which case $\mathrm{ASCDR}^i = m^i + n^i \cdot \mathrm{ASCDR}$ for all i and Equation (2) would again reduce to Equation (1).

We have already seen evidence that neither of these conditions strictly applies. However, there are certain combinations of causes of death wherein one of the conditions is met sufficiently well that separate enumeration of the causes adds little explanatory power, while subtracting considerable economy from the presentation. In short, it is not necessary to deal with all twelve causes of death in order to demonstrate the importance of cause-structure for age-structure. Consideration of a and b, together with additional information about coding practices, led to the following choice of categories

I. Tuberculosis
II. Other infectious and parasitic diseases
III. Respiratory disease (influenza/pneumonia/bronchitis)

IV. Diarrheal disease and certain diseases of infancy
V. All violence
VI. Maternal complications (females only)
VII. All other and unknown

Diarrheal diseases are combined with certain diseases of early infancy not simply because of the similarity of their age patterns of influence. Under the 6th and 7th Revisions of the International List of Causes of Death, deaths from diarrhea in the first four weeks of life are assigned to CDEI, an assignment not operative in other Revisions. Moreover, deaths from "toxicosis" under age 1 are assigned to CDEI, although the principal cause of this condition is diarrhea. According to Verhoestraete and Puffer (1958, p. 27), this important coding peculiarity in Latin America frequently prevents diarrhea from emerging as the leading cause of death in infancy, and improperly projects CDEI into this position.

Table 5.5 presents the regression equations that relate age-specific death rates, in the form of $(-\log {}_{n}p_{x})$, to age-standardized death rates from these 6 or 7 causes. The final column displays the proportion of variance left unexplained by the regression equation using all causes combined (from Table 5.3) that is explained when information on these 6–7 causes is introduced. On average, 49% of the unexplained variance can be accounted for by cause of death structure. The figure rises to 59.9% if all twelve causes are separately included. Thus, it is justifiable to conclude that roughly half of the variance in age-curves of mortality at a particular mortality level can be accounted for by variance in relative importance of 6–7 cause of death categories among populations at that level. This is the principal result of this chapter, and it suggests that causes of death have substantial value in accounting for disparities in age patterns of mortality.

Since the dependent variables in Table 5.5 are negative cumulations of death rates, it should be the case that higher mortality from a particular cause is associated with lower values of the dependent variables; that is, the coefficients should be negative. In fact, 59 out of the 75 coefficients presented are negative, or 79%. The causes whose variation is most significant for mortality at a particular age can best be gauged by the standardized beta coefficient: the coefficients presented in Table 5.5 multiplied by (σ^{i}/σ_{x}), where σ^{i} is the standard deviation of the age standardized death rate from cause i and σ_{x} is the standard deviation of the dependent variable. The standardized beta coefficient indicates the change in the dependent variable (expressed in standard deviation units) produced by a one-standard-deviation change in the independent variable.

Table 5.6 lists the causes of death having the largest standardized beta coefficients in the various age intervals. At ages 0–1 and 1–4 for both sexes, a one standard deviation change in the combination, diarrhea and certain

Table 5.5 Coefficients of regression equations relating age-specific death rates from all causes combined to age standardized death rates for particular causes, $N = 163$

Dependent variable	Constant	Coefficient of tuberculosis	Coefficient of infectious and paras.	Coefficient of respiratory	Coefficient of diarrheal and cert. dis. of infancy	Coefficient of violence	Coefficient of other & unknown	Coefficient of maternal	R^2	Proportionate reduction in unexplained variance from introduction of information on causes of death
FEMALES										
$\log(l_1/l_0)$	.00866	−9.9285	10.8098	−14.9013	−30.5294	8.4661	−2.5468	−58.7727	.937	.500
		(3.3306)	(2.7983)	(2.0959)	(2.4384)	(11.8654)	(1.1025)	(21.2818)		
$\log(l_5/l_1)$	.02004	−6.1873	−20.3757	−4.2076	−20.0184	4.3736	−2.0869	31.3303	.947	.558
		(2.3737)	(1.9943)	(1.4937)	(1.7378)	(8.4561)	(.7858)	(15.1670)		
$\log(l_{20}/l_5)$	.01265	−14.0136	−13.8533	.5256	−2.3515	2.9396	−2.5863		.955	.521
		(1.1926)	(1.0540)	(.7608)	(.9293)	(4.4175)	(.4138)			
$\log(l_{40}/l_{20})$	.02142	−34.1307	−10.0233		−3.0013	−8.2513	−4.9133	−132.1588	.960	.621
		(2.4470)	(2.6321)		(1.7830)	(9.2271)	(.8587)	(15.7858)		
$\log(l_{60}/l_{40})$	.00902	−15.1575	−15.0771	−11.0574	7.1795	−79.2064	−11.5012	−217.8493	.908	.394
		(5.5709)	(4.6805)	(3.5057)	(4.0784)	(19.8461)	(1.8441)	(35.5961)		
$\log(l_{80}/l_{60})$	−.21010	25.3880	−47.3659	−81.5535	10.0419	−113.3955	−74.5970	331.710	.912	.338
		(15.9044)	(13.3625)	(10.0084)	(11.6435)	(56.6589)	(5.2648)	(101.6238)		
									Mean	.489
MALES										
$\log(l_1/l_0)$	.02454	−10.7699	−1.6411	−13.5127	−31.9127	−17.4076	−1.8465		.929	.445
		(3.1820)	(2.9641)	(2.0318)	(2.6373)	(4.5058)	(1.1565)			
$\log(l_5/l_1)$	.02610	−.9512	−22.3760	−2.6001	−16.8333	6.0128	−2.6772		.925	.570
		(2.1811)	(2.0317)	(1.3927)	(1.8078)	(3.0885)	.7927			
$\log(l_{20}/l_5)$	.00579	−5.3421	−16.6080	−.3039	−1.8474	−4.9403	−1.1097		.910	.516
		(1.2358)	(1.1511)	(.7891)	(1.0242)	(1.7499)	(.4491)			
$\log(l_{40}/l_{20})$	.02524	−31.6330	−18.0716	−2.5905	−4.8679	−37.5044	−2.0634		.935	.549
		(2.5301)	(2.3569)	(1.6156)	(2.0971)	(3.5827)	(.9196)			
$\log(l_{60}/l_{40})$	.03922	−36.1242	−10.8434	−15.5975		−56.8239	−15.8312		.916	.344
		(4.7289)	(3.8911)	(2.8852)		(6.7189)	(1.7143)			
$\log(l_{80}/l_{60})$	−.18828	37.1778	19.9587	−65.3533	8.9527	20.0802	−98.5621		.848	.531
		(15.6107)	(14.5417)	(9.9678)	(12.9386)	(22.1050)	(5.6738)			
									Mean	.493

Table 5.6

Causes of death with largest standardized beta coefficients at a particular age

Age	Females	Males
0–1	Diarrhea/cert. dis. of infancy	Diarrhea/cert. dis. of infancy
1–4	Diarrhea/cert. dis. of infancy	Diarrhea/cert. dis. of infancy
5–20	Infectious and parasitic	Infectious and parasitic
20–40	Tuberculosis	Tuberculosis
40–60	Maternal	Tuberculosis
60–80	Other and unknown	Other and unknown

diseases of early infancy, has the largest effect on death rates. This combination consists almost exclusively of diarrhea at age 1–4. Infectious and parasitic, tuberculosis, and other and unknown emerge as the most important sources of variation at progressively higher ages. It is important to note that these are not necessarily the most important causes at these ages but rather the causes that are most likely to act independently to create variation in age-specific death rates. If a nation exhibits an unusual death rate in a particular age interval, Table 5.6 identifies the cause of death most likely to be responsible.

The one unexpected finding in the table is that maternal mortality variation is more influential than variation in any other cause of death for female death rates in the age interval 40–60. This is unexpected because maternal mortality has by far the lowest mean and variance of any causes under consideration; moreover, the large majority of deaths from the cause are recorded in the age interval 20–40 rather than 40–60. It is clear that recorded deaths from maternal mortality are acting as an indicator of a more general health disadvantage suffered by middleaged women in some populations. It may be the case that a heavy burden of childbearing combined with poor health standards continues to exert an effect on mortality well past the end of the childbearing period itself. Kitagawa and Hauser (1973) find support for this contention in United States data. Or it may be that the same factors producing high death rates from maternal mortality (e.g., low status of women leading to poor access to nutrition and medical care, high rates of childbearing) influence mortality from many causes, of which maternal mortality is the best proxy for the underlying factor.[3] In either case, the indirect approach pursued here has revealed a tendency that would not have been suggested by a more direct, decompositional approach to the raw data.

[3] These issues are considered in more detail in Chapter 6.

Illustration of the Importance of Cause-of-Death Structure for Divergencies in Age Patterns of Mortality: The Coale–Demeny Models

If the age pattern of mortality in a population at a certain level of life expectancy is influenced by its cause of death structure, then one should be able to attribute differences in age patterns of mortality in two or more populations at the same level at least partially to differences in their cause structures. Systematic and persistent regional differences in age patterns have been identified by Coale and Demeny (1966) on the basis of an exhaustive review of published life tables. They identified four distinct regional patterns in European populations: the "North," with low infant mortality and low mortality above age 50 and high mortality in the middle adult years; the "South," with high infant mortality and even higher relative mortality in the range of 1–5 years; the "East," with high infant mortality and high mortality above age 60; and the "West," which showed no systematic pattern of deviations from the average when all regions were com-

Table 5.7

Age-standardized crude death rates from all causes and specific causes in five populations[a]

	Males		Females		
Disease	England & Wales, 1871, $e_0^0 = 39.16$	Italy, 1891, $e_0^0 = 38.48$	U. S., 1940, $e_0^0 = 65.43$	Norway, 1930, $e_0^0 = 65.78$	Portugal, 1960, $e_0^0 = 66.72$
Respiratory tuberculosis	.00260	.00091	.00033	.00120	.00024
Other infectious and parasitic	.00389	.00355	.00028	.00055	.00021
Influenza/ pneumonia/ bronchitis	.00400	.00338	.00083	.00095	.00096
Diarrheal and cert. dis. of infancy	.00232	.00449[b]	.00057	.00047	.00134[c]
Violence	.00125	.00067	.00063	.00017	.00027
Maternal	—	—	.00012	.00009	.00005
All other	.01335	.01436	.00883	.00702	.00695
All causes	.02741	.02736	.01159	.01045	.01002

[a] S. Preston, N. Keyfitz, and R. Schoen (1972).
[b] Diarrheal = .00313; Cert. dis. of infancy = .00136.
[c] Diarrheal = .00067; Cert. dis. of infancy = .00067.

bined. It will be recalled from Chapter 2 that members of the West pattern were highly disproportionately represented among populations with the most "normal" cause of death structures. Because of the heavy use which the Coale–Demeny patterns have received in demographic applications, our illustrations will focus on comparison of representatives of these regional patterns.

England and Wales and Italy provide the earliest data on causes of death of any populations in these regional groups. England and Wales belong to the "West" regional group and Italy to the "South." Table 5.7 presents the male age-standardized crude death rates from the six causes for England and Wales in 1871 and for Italy in 1891. The life expectancies of the two populations are quite close at 39.16 and 38.48. The cause-of-death structure differs substantially in the two cases, however, with England and Wales exhibiting higher death rates from tuberculosis and "other infectious and parasitic diseases." Italy's death rate is much higher from diarrheal diseases/certain diseases of infancy, of which the former entity is the more important.

The age sequence of death probabilities in the two populations (Preston *et al.*, 1972) are presented graphically in Figure 5.2. The pattern of deviations agrees with that noted by Coale and Demeny. In order to determine whether this pattern of differences could have been predicted on the basis

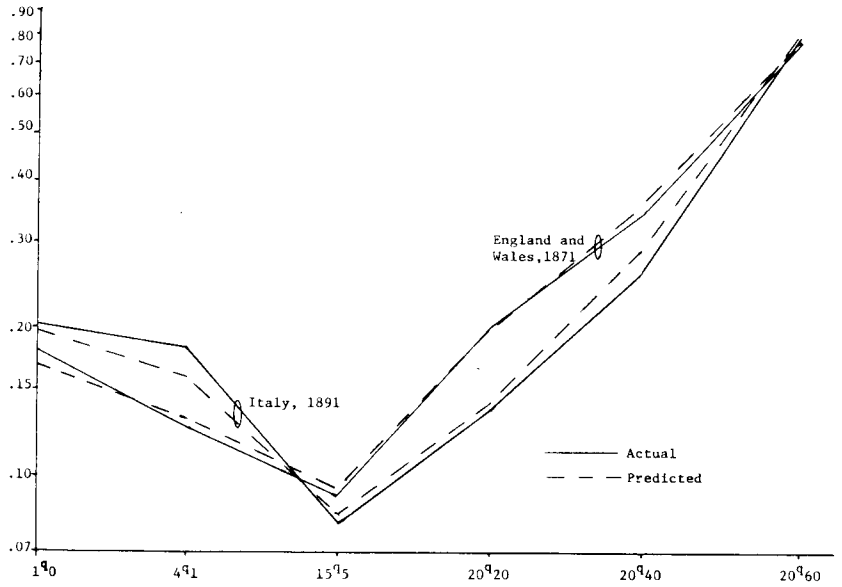


Figure 5.2 Actual and predicted death probabilities in two male populations

of the causes of death structure prevailing in the two populations, we can enter the standardized death rates by cause in the two populations (Table 5.7) into the male regression equations of Table 5.5. The sequences of death rates predicted in this fashion should differ for the two populations in the same manner as do the sequences of actual death rates. The predicted death rates are also plotted in Figure 5.2.

Figure 5.2 demonstrates strikingly that the actual age patterns of mortality are accurately predicted by the regression equations in combination with recorded cause-specific mortality in both England and Italy. Hence, the discrepancy in their age patterns is also accurately predicted. Knowledge of the cause-of-death structures proves to be of great value in understanding the source of disparity in the two age curves.

A similar comparison can be made among representatives of three of the regional patterns at a higher level of life expectancy. Table 5.7 presents the female age-standardized death rates from the seven causes in the United States, 1940, Norway, 1930, and Portugal, 1960. The life expectancies in these populations are, respectively, 65.43, 65.78, and 66.72. The Northern representative, Norway, displays the highest death rate from tuberculosis and other infectious and parasitic diseases. The Southern country again displays the highest death rate from diarrheal/certain diseases of infancy. The United States, from the "West," is intermediate in these important causes.

Probabilities of dying in the three countries are plotted in Figure 5.3 and compared to the probabilities predicted on the basis of a country's cause structure in combination with the "female" equations on Table 5.5. Once, again, divergencies are predicted rather well on the basis of the respective cause-of-death structures. The ranking of the three countries is predicted correctly at all ages except infancy, where the order of the United States and Norway is reversed. Thus seventeen of the eighteen rankings of death probabilities in any pair of these three countries are preserved in the predictions.

Many other examples of such comparisons could be presented. Czechoslovakia in 1934 is the only available representative of the "East" pattern before World War II. When compared to New Zealand, 1881, at the same general level of mortality, Czechoslovakia had higher death rates in infancy and ages 60–80 (typical of the East group) and much higher death rates from respiratory and diarrheal diseases. Consequently, their differences in cause-of-death structure are predicted quite accurately. In more recent years, however, members of the "East" family show infant mortality rates substantially higher than predicted levels, suggesting that the unusually high infant mortality in this bloc is a product of unusually high infant mortality from particular causes of death, rather than of the cause-of-death structure itself.

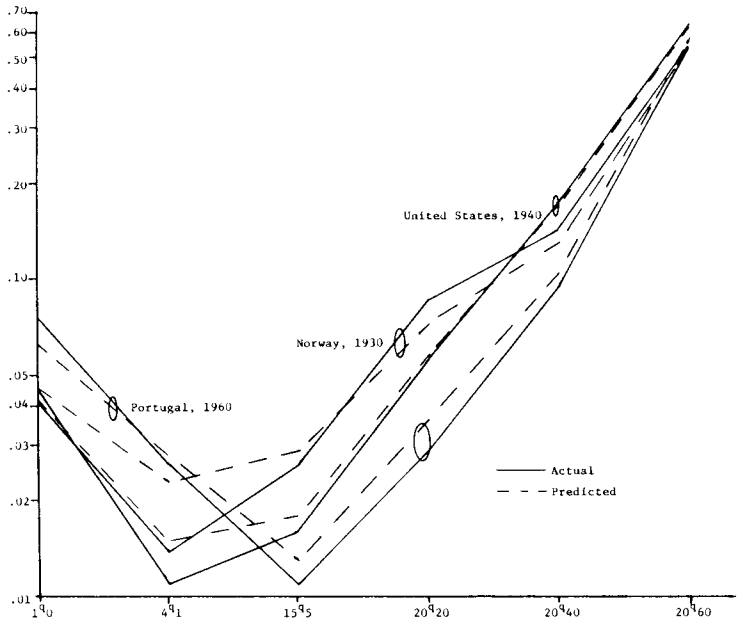


Figure 5.3 Actual and predicted death probabilities in three female populations.

The age structure of mortality in many non-Western nations can be predicted as accurately as that of western countries at the same level of life expectancy. For recent years, the male populations of Chile, Colombia, Costa Rica, Mexico, Panama, Trinidad and Tobago, Venezuela, and the Republic of South Africa (coloured) all show predictions in close accord with reality. One important exception is Guatemala, where predicted death rates in infancy exceed the actual death rate, itself quite high, by about 50%. The reason may be an overrecording of deaths to diarrheal diseases, or gastroenteritis. A review of coding accuracy determined that the number of deaths returned in this category was about three times higher than it should have been among adults in Guatemala City in 1962–64 (Puffer and Griffith, 1967, pp. 238, 327). Predictions of infant mortality are also substantially too high in Taiwan, perhaps because of problems in reporting ages of infants.

As demonstrated in Chapter 2, cause-of-death structures in the non-Western nations contained in this analysis are, as a group, highly similar to those of western nations at equivalent levels of mortality. The two persistent differences are relatively high death rates from diarrheal diseases in the non-Western areas and low death rates from cardiovascular diseases. It was argued that the relatively high death rates for diarrheal diseases in

non-Western areas probably represent a slower improvement in nutritional standards and sanitation, of central importance in the etiology of deaths from these diseases, than in medical technology, principally influential against the infectious diseases caused by specific and identifiable micro-organisms. Since southern European countries share abnormally high rates of death from diarrheal diseases, they will typically provide a more accurate model of mortality relations for non-Western areas than will other European regions. United Nations Manual IV (1967, p. 72) notes that Mexico, with virtually complete vital registration, has a mortality pattern much closer to the "South" than to the "West." Sullivan (1973) confirms the importance of diarrheal disease for age patterns of mortality by tracing changes in the Taiwanese pattern between 1957 and 1968 to a rapid reduction in diarrheal death rates.

Turning the Problem on Its Head: Causes of Death and the "African Standard"

Just as the cause-structure of mortality can be used to predict the age pattern, the age pattern implies a special cause of death structure. We illustrate the usefulness of this reversal by reference to the Brass "African standard" mortality schedule (Brass and Coale, 1968). This standard incorporated what were considered characteristic features of tropical African mortality. In particular, the pattern exhibits relatively high death rates between ages 5 and 20 relative to those at ages below 5, and exceedingly high death rates above age 20 relative to those below 20. Brass and Coale cautiously state that "Whether these common features are a characteristic bias in African data or a characteristic feature of African mortality is a matter of conjecture" (p. 133). In any case, it was clear that use of one of the existing European models would have been suspect.

One gauge of the authenticity of the "African standard" is the plausibility of the cause of death structure which it implies. Since Table 5.5 provides six equations for age-specific rates and there are six cause-specific death rates that enter as variable into each equation, once we are presented with a set of $\log {}_np_x$'s we could solve directly for the level of the six unknowns, ASCDR^i ($k = 1, \ldots, 6$). This is the least arbitrary approach to the question but the most risky since it uses no information on the typical level of mortality from various causes; moreover, nothing prevents negative values of ASCDR^i from emerging in the process. Here we use a simpler technique that is more likely to yield reasonable and interpretable numbers, although it is admittedly quite arbitrary. We begin with the cause of death structure

typical of a population at the level of mortality under consideration and see how its cause of death structure might reasonably be modified in order to reproduce approximately the recorded age-structure of mortality.

A portion of the African standard $p(x)$ function is presented in Table 5.8. $p(1)$ (for both sexes) is .880, which corresponds approximately to the $p(1)$ for ASCDR = .0205 in Table 5.3. The typical cause of death structure corresponding to an ASCDR = .0205 is determined by use of the linear regressions relating $ASCDR_i$ to ASCDR that were presented in Chapter 2, substituting ASCDR = .0205 into the equations. Predicted death rates for males are as follows: Tuberculosis, .00127; Other Infectious and Parasitic, .00142; Respiratory, .00306; Diarrheal and Certain Diseases of Infancy, .00189; Violence, .00106; Other and Unknown, .01130. The age-curve implied by this combination of causes, when substituted into male equations of Table 5.5, is also shown in Table 5.8. In order to reproduce very closely the "African standard" $p(x)$ function, we multiply the "average" death rate from tuberculosis by 2.00, from infectious and parasitic diseases by 2.75, and from diarrheal and certain diseases of infancy by .6, and once again apply equations in Table 5.5. The resulting $p(x)$ column, shown in Table 5.8, does not differ from the African standard by more than .006 through age 60.

In other words, the African standard age-pattern is consistent with death rates from tuberculosis and infectious and parasitic diseases which are

Table 5.8

Comparison of three survivorship functions (probability of surviving from birth to age x)

Age (x)	Cause-of-death regressions, average structure of causes corresponding to ASCDR = .0205. Males[a] (1)	Cause of death regressions, structure of causes same as (1) but death rate from tuberculosis multiplied by 2.00, infectious and parasitic 2.75, and diarrheal and cert. dis. of inf. by .6. Males[a] (2)	African standard (both sexes)[b] (3)
0	1.000	1.000	1.000
1	.876	.882	.880
5	.816	.786	.786
20	.779	.715	.713
40	.690	.584	.590
60	.506	.398	.398
80	.127	.109	.076

[a] Tables 5.3, 5.5, and text.

[b] W. Brass and A. Coale (1968).

approximately 2–3 times higher than normal for a population at that approximate level of mortality. In view of the overriding importance of malaria in tropical Africa, this implication seems quite acceptable. In fact, malaria has an age curve of mortality intermediate between that of tuberculosis and other infectious and parasitic diseases, excluding both malaria and tuberculosis. For example, of these three categories in Thailand, 1964—the country with highest malarial death rates in World Health Organization statistics of that year—"other infectious and parasitic" has the highest death rate under age 15, malaria between ages 15 and 25, and tuberculosis thereafter.[4] Except at ages 15–25, malaria's rates are always intermediate. The lower than normal death rates from diarrheal diseases implied by this procedure seems consistent with a below average density of living conditions in tropical Africa.

By the same token, unusually high death rates from infectious diseases cannot account for the African standard's exceptionally high death rate at ages 60–80. This feature could be produced by an increment in the "other and unknown" death rate (which, in Table 5.5, has an impact on death rates six times greater in this age interval than in any other). On the other hand, it could easily be bogus. There is surely very little solid information upon which to base estimates of death rates for this group in Africa, in light of pervasive misreporting of age and relatively small numbers of persons. That this feature of the standard age pattern is far out of line with a plausible cause of death structure that accounts quite well for age patterns up to age 60 is some reason to doubt its validity.

Model Mortality Patterns Based on Causes of Death

Model mortality patterns are typically required for demographic estimation only if death registration is incomplete. But if the degree of incompleteness is largely invariant with respect to cause of death, then the cause-structure of mortality can be reliably estimated. In such a case the age pattern of mortality should be largely recoverable without reference to any external models. The level of mortality can then be estimated through conventional stable population or census survival techniques. Two situations can be distinguished in which knowledge of causes of death may provide useful guidelines for model construction.

[4] World Health Organization (1964, pp. 126–7, 260–61). While malaria is nominally a member of the "other infectious and parasitic" category, its death rates in the sample are typically too low to have influenced the characteristics of this aggregate.

Situation 1: Age-specific death rates are available by cause of death. Deaths are underrecorded but not differentially by cause. Deaths are assumed to be differentially underrecorded by age.

In this situation, the age-cause specific death rates could be converted into age standardized crude death rates by cause through direct application of the standard population's age distribution (Chapter 1). This set of age-standardized death rates could then be inserted into regression equations presented in Table 5.5, yielding a first approximation to the age curve of mortality. This approximation presumably results in too low a level of mortality, one that is inconsistent with recorded age distributions. In order to adjust the level of mortality, one must simply solve for the level of a multiplier K of all estimated ASCDR^i's that is in best agreement with external evidence. The multiplication of each ASCDR^i by the same constant is consistent with the assumption that there is no differential omission of deaths by cause. This procedure makes little use of the recorded *age* structure of mortality; there is often good reason to ignore such information, since differential omission by age is probably more frequent than differential omission by cause of death.

Situation 2: No information exists on ages at death. Total deaths are available by cause, together with a recorded age distribution. Deaths are underrecorded but not differentially by cause.

In this situation the availability of cause of death information is potentially more valuable than in the prior case because no information at all exists on ages of death. Since the age distribution is known, together with the crude death rate by cause, conventional indirect standardization can be used to make an initial estimate of the level of ASCDR^i for all i. Since the "standard" age curve of mortality from a particular cause often varies with the level of mortality from that cause, the standard should be selected from among the age curves (available in Table 5.1) on the basis of the best initial guess regarding probable mortality level. Once these estimates are available, the procedure is identical to that of Situation 1: use equations in Table 5.5 and solve for the level of that set of ASCDR^i's that is most consistent with external evidence.

In both cases the series of age-specific death rates could be estimated directly and converted by conventional actuarial means into a life table. By use of the regression equations, however, this tedious intervening step can be averted and the set of death rates readily converted into life table parameters.