Beyond 'best practices': Waiting times to life expectancy improvements

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Abstract

We propose a novel country-level life expectancy analysis. Sojourn time is the amount of time a country spends in a given life expectancy interval. We analyze all available data from the Human Mortality Database, calculating sojourn times for one-year increments in life expectancy. The preponderance of the evidence points to no increase in sojourn time as life expectancy increases. This supports the notion that life expectancy will continue to expand worldwide. Unlike the so-called "best practices" analysis, the present work considers more than one country at a time, so this is a useful corroboration of existing findings. We also explore one aspect of this analysis that is a useful reminder of the potential pitfalls of sample selection in the analysis of aggregate mortality data.

Introduction

Some recent work on mortality has focused on the extension of "best practice" life expectancy: the national world-record life expectancy at any given point in time. The seminal paper is Oeppen and Vaupel (2002), which demonstrated that a regression line through the world-record female life expectancy vs. time graph gives an excellent fit, with a slope of about one-quarter year of life expectancy, e(0), per year of time. Since national populations are large, there is no reason to believe that the world-record e(0) at a given point in time should be unattainable in the future by other countries. This is one way in which country-level mortality differs from individual-level mortality, despite the former being an aggregate of the latter. Regardless of future gains in life expectancy, it is hardly likely that the longest life at the individual level — the current record is 122 years (Robine and Allard 1999) — would be attainable by everyone, no matter how salubrious the conditions may be. However, it is much more plausible to say that at the national level, many countries can aspire, through continued health and nutrition improvements, to achieve e(0)$\geq$86.4, which was the level of Japanese females in 2009 according to the Human Mortality Database. Whether e(0)$\approx$86.5 years represents a ceiling, or is simply the current record, is part of the debate; this should not diminish the point that life expectancies and individual life spans are not directly comparable.

« more literature review/context-setting here »

More recently, Vallin and Meslé (2009, 2010) questioned the broader applicability of Oeppen and Vaupel's (2002) findings, noting that a piecewiselinear fit is more appropriate, and questioning the idiosyncratic nature of the sample selection.

Objectives

In this study, we examine the same data as Oeppen and Vaupel (2002) and their interlocutors Vallin and Meslé (2009, 2010) (+others), but we use a different analytic framework. In stochastic processes, a waiting time is the cumulative time taken to achieve some event, and a sojourn time is the difference between waiting times of consecutive states, or the amount of time a system spends in a certain state (Taylor and Karlin 1998). Rather than consider best-practice life expectancy, which is one country at a time, we analyze sojourn times at one-year intervals of e(0), for every country in the Human Mortality Database (HMD).

One benefit of sojourn time analysis is that a richer data set is generated from the master HMD data. Rather than considering one country at a time, we examine the mortality transition, at all e(0) levels, for every available country. Thus, fewer data are discarded. However, we believe that the principal benefit of our approach is that it examines the existing data in a novel way (to the best of our knowledge). The relationship between sojourn times and e(0) level can be revealing: secular increases in sojourn times would mean that it is harder for countries to achieve one-year gains as e(0) increases. Extrapolation of such a finding would imply that the Oeppen and Vaupel (2002) trend is unlikely to continue to hold in the future. On the other hand, lack of a relationship between e(0) and sojourn time would, in some sense, be analogous to Oeppen and Vaupel's (2002) finding, implying that one-year gains in e(0) are not harder to achieve as e(0) increases.

Materials and methods

We obtained all available data on period life expectancy at birth from the Human Mortality Database.[1] This is the first analysis of its kind of which we are aware, so we analyze data for both sexes combined. The data were analyzed as described below using the IDL programming language.[2]

We establish, *a priori*, a list of life expectancy values, the sojourn times between which will be calculated. We call these values "targets". For simplicity, we use integer values of life expectancy (30 years, 31 years, . . .) as the targets. Once a given target is attained, the "sojourn time" to the next target is the number of years it takes to meet or exceed the next target.

At the beginning of the data for any given country, sojourn times are unknown. For example, the earliest observation in the HMD is for Sweden in 1751: e(0)=38.35. Thus, we cannot establish the sojourn time for the target e(0)=38. The target e(0)=39 was attained in 1753, so the first discernible sojourn time is 2 years (1753−1751), between e(0)=38 and e(0)=39.[3] Lacking data before 1751 (i.e., lacking any evidence to the contrary), our method assumes this was the first time e(0)=39 was surpassed. The computer program sorts through each country to observe all attained targets and their sojourn times.

Results and discussion

Figure 1 is a scatterplot of sojourn times for life expectancy attainment. The horizontal axis plots the target life expectancy values, and the vertical axis is the time taken to achieve that value from the previous target (viz., the sojourn time). Targets are spaced from 31 to 83 in one-year increments, and the scatterplot has been jittered (Cleveland 1993) to prevent perfectly-overlapping points from appearing as one.

The outlier in upper left of figure 1 is an observation for Sweden, with coordinates (e(0) target=43, sojourn time=44). This breaks down as follows: in 1780, Swedish life expectancy surpassed 42.0 for the first time in the database (it was 42.70, breaking the previous record of 41.50 from 1776). It took another 44 years (to 1823, e(0)=45.19) to surpass life expectancy of 43.0; thus, the point (43,44) in the scatterplot. Surpassing more than one target at a time is denoted by a zero value on the vertical axis. For example, when Swedish life expectancy reached 45.19 in 1823, it was the first time that life expectancy surpassed not only 43, but also 44 and 45. Thus, we coded the sojourn time for e(0)=44 and e(0)=45 as being zero.

As figure 1 shows, the relatively large number of observations at zero sojourn time — especially at e(0) targets below 71 — shows that large jumps in e(0) were not unusual. The drift upward on the bottom right of the scatterplot indicates that at the higher e(0) values, typical of the late twentieth and early twenty-first centuries, it is harder to jump more than one year of life expectancy at a time. At e(0)=72 and above, no country in the database has ever jumped more than one year of life expectancy in a single step (year).

The shaded regions in figure 1 are two "prongs" of outliers with unusually long sojourn times to achieve a one-year increase in life expectancy. It is noteworthy that these occur at medium-low (40 to 55) and medium-high (67 to 74) levels of life expectancy, but not in-between, nor at the extremes

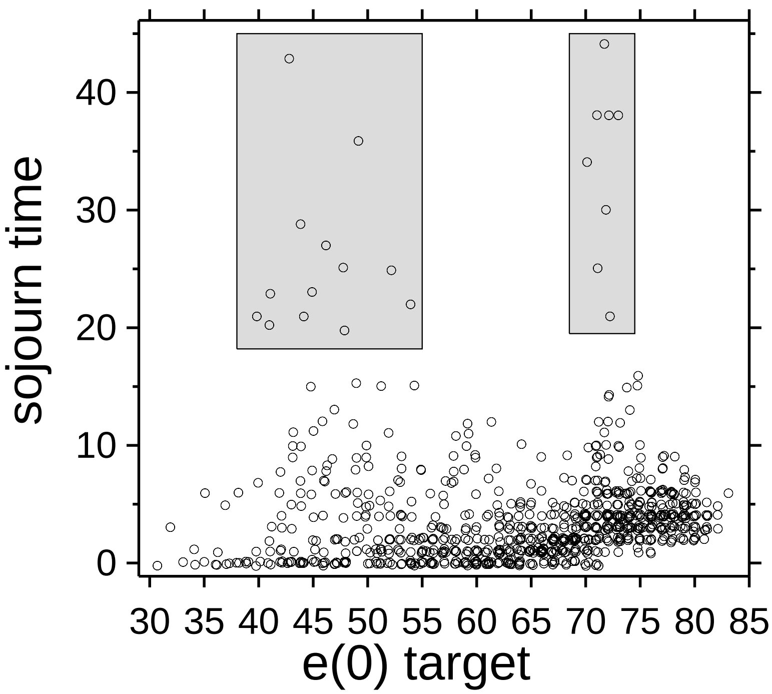

Figure 1: Jittered scatterplot of sojourn times for attainment of target (time to target) versus target value.

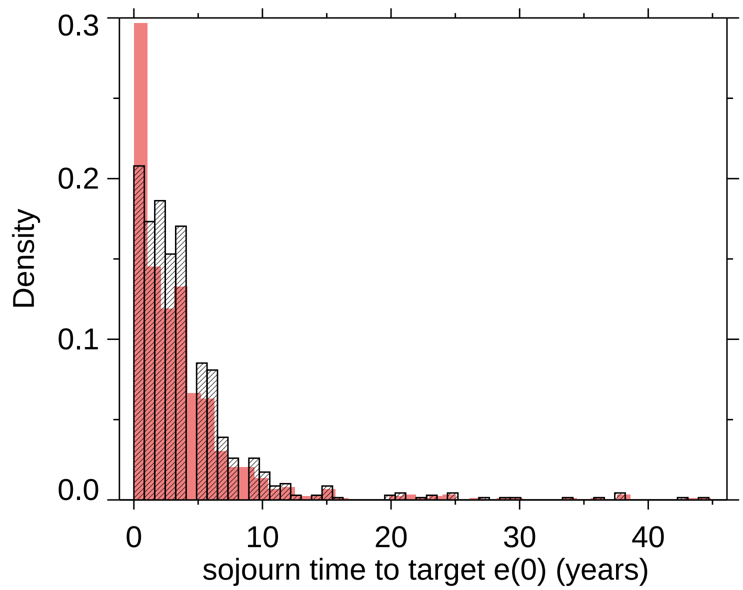

Figure 2: Histogram of sojourn times in figure 1, divided into two groups: e(0)≤67 (shaded) and e(0)>67 (cross-hatched).

of the distribution along the horizontal axis. Figure 2 presents histograms of the sojourn time to a one-year improvement of life expectancy (i.e. of the values on the vertical axis of figure 1), divided into e(0)≤67 (shaded) and e(0)>67 (cross-hatched)[4]. The histogram shows that the sojourn time distribution is reasonably symmetric above and below the cut-point of e(0)=67. The shaded bars (e(0)≤67) reflect a greater relative mass at zero sojourn time compared to the hatched bars (e(0)>67). At lower life expectancy, there is more year-to-year volatility,[5] and therefore surpassing two targets at once (which we denote as zero sojourn time for the second target) is more common.

Figures 3 and 4 show sojourn times versus target on a country-by-country basis for all 40 countries in the HMD, arranged alphabetically by country abbreviation. Disaggregating by country clarifies the components of the prongs in figure 1. Most countries do not follow the U-shaped pattern that is shown in the aggregate (i.e., in figure 1). The country-level series are noisily flat, with greater year-to-year volatility seen in the 19th century and prior.[6]

The volatility of 19th-century and prior mortality swings account for the left prong. Years in which mortality was unusually low could set-up long

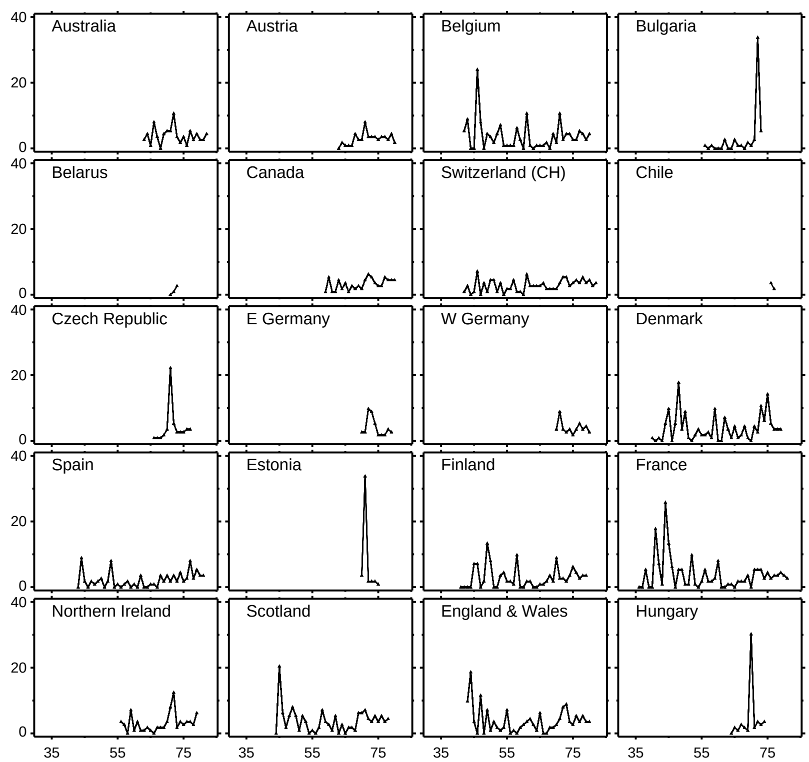

Figure 3: Country-specific line plots of sojourn times for attainment of target (time to target) versus target value. Continues in figure 4.

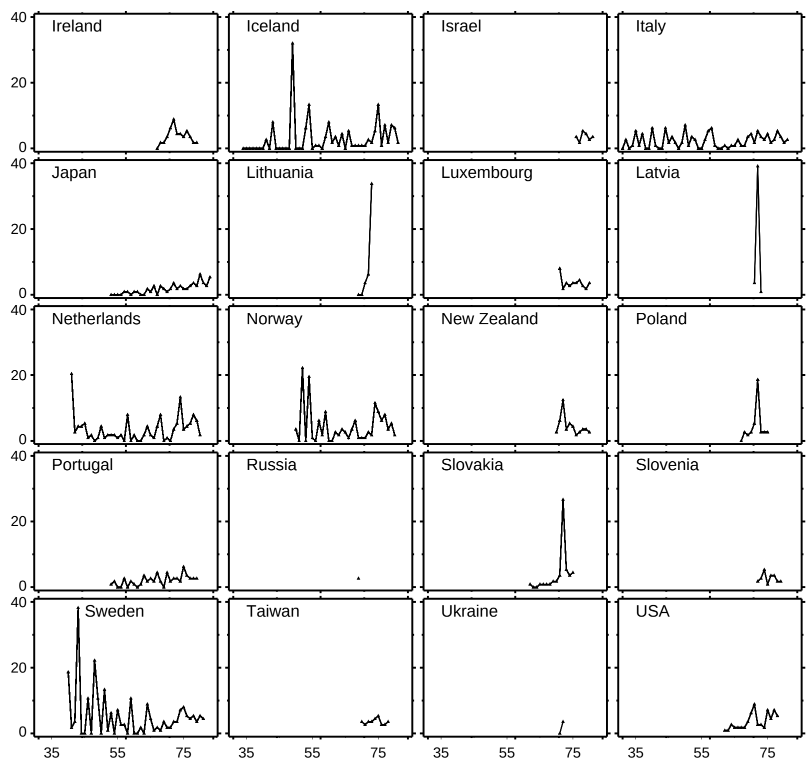

Figure 4: Country-specific line plots of sojourn times for attainment of target (time to target) versus target value. Continuation of figure 3.

waits until the next target was surpassed. For example in 1780, Swedish life expectancy was 42.70, which was a record to-date, and also a very mild year in a volatile mortality climate: 1779 was 32.81 and 1781 was 37.83. Because 1780 was, by contemporary standards, such an unusually fortunate year in the swings of mortality, it took many years to surpass it. As mortality declined, its year-to-year volatility also decreased. The extremely long waits for a one-year improvement that were set up by this volatility also disappeared.

Stalled mortality transitions in eastern Europe and the former Soviet Union similarly provide a particularistic explanation of the right prong in figure 1. The eight outlier points making up the right prong correspond to observations from Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, and Slovakia. The country series (figures 3 and 4) show that these countries achieved short sojourn times for mortality improvements, punctuated by long spells of stagnation. For example, Hungary first achieved e(0)=69 in 1961, a speedy improvement from e(0)=68, first attained in 1960. However, Hungarians had to wait 34 years — until 1995 — before achieving e(0)=70. An extreme instance is Russia, which achieved e(0)=69 in 1963 but has yet to hit the e(0)=70 target, as of the most recent (2010) data.

The prongs on either side of figure 1 come from sample composition. The HMD database includes a few countries with time series of mortality data going back to the 19th century and before, and a few different countries with idiosyncratic stalled Cold War mortality transitions. Therefore, we cannot infer that the evolution of a given country will recapitulate the U-shaped picture of figure 1. To quantify and test this, we ran regressions on the panels in figures 3 and 4, testing linear and quadratic specifications.

Table 1 gives OLS regression results for fitting a straight line through each of the panels in figures 3 and 4. Only six countries show a statistically-significant linear trend in the panels. That is to say, the linear trend through most of the panels of figure 3 is indistinguishable from a flat line. In those countries, the expected sojourn time for one-year improvements in life expectancy does not change with life expectancy level (assuming a straight-line specification). MORE HERE?

Relaxing somewhat the straight-line assumption, table 2 presents results for fitting a quadratic regression models to each of the panels in figures 3 and 4. Here also, most coefficients are not statistically significant, with seven countries having a significant ($p \leq 0.05$) $(\text{e(0) target})^2$ coefficient. Of these, two are negative, suggesting decreasing sojourn times for life expectancy improvements, while the other five show increasing sojourn times. However, close inspection of the individual cases reveals that the significant quadratic

Table 1: OLS regression (straight-line) results for the panels in figures 3 and 4.

Country	**α**	**SE**	**β**	**SE**	p	R^2
Australia	6.15	7.98	-0.02	0.11	0.82	0.00
Austria	-8.14	6.25	0.16	0.09	0.09	0.17
Belgium	8.29	4.40	-0.07	0.07	0.35	0.02
Bulgaria	-43.66	23.91	0.73	0.37	0.07	0.20
Belarus	-106.67	20.79	1.50	0.29	0.12	0.96
Canada	-6.41	3.94	0.14	0.06	0.02	0.25
Switzerland	-0.53	1.58	0.06	0.03	0.02	0.12
Chile	156.00	0.00	-2.00	0.00	.	1.00
Czech Republic	-9.50	40.89	0.20	0.57	0.73	0.01
E Germany	34.40	27.10	-0.40	0.36	0.30	0.13
W Germany	17.41	15.36	-0.17	0.20	0.42	0.07
Denmark	1.41	3.84	0.05	0.06	0.44	0.02
Spain	-0.99	2.27	0.06	0.04	0.13	0.06
Estonia	262.95	253.70	-3.51	3.50	0.37	0.20
Finland	1.97	3.15	0.02	0.05	0.69	0.00
France	8.75	3.65	-0.08	0.06	0.22	0.03
Northern Ireland	-5.41	6.27	0.13	0.09	0.17	0.09
Scotland	7.43	4.38	-0.05	0.07	0.48	0.01
England & Wales	7.82	3.98	-0.06	0.06	0.37	0.02
Hungary	-34.43	65.82	0.57	0.95	0.56	0.04
Ireland	-1.94	14.77	0.08	0.20	0.69	0.01
Iceland	-0.72	3.76	0.07	0.06	0.27	0.03
Israel	-0.49	29.59	0.06	0.38	0.89	0.01
Italy	1.07	1.28	0.03	0.02	0.23	0.03
Japan	-8.97	1.46	0.16	0.02	0.00	0.66
Lithuania	-579.50	239.03	8.30	3.37	0.09	0.67
Luxembourg	24.13	16.14	-0.27	0.21	0.25	0.16
Latvia	124.33	1725.23	-1.50	23.96	0.96	0.00
Netherlands	3.13	3.84	0.01	0.06	0.84	0.00
Norway	8.48	8.05	-0.05	0.12	0.66	0.01
New Zealand	37.73	22.51	-0.44	0.30	0.18	0.19
Poland	-32.98	59.42	0.53	0.84	0.54	0.05
Portugal	-5.64	2.41	0.12	0.04	0.00	0.31
Russia						
Slovakia	-51.86	32.53	0.82	0.47	0.11	0.20
Slovenia	10.19	19.97	-0.10	0.26	0.73	0.02
Sweden	17.23	6.19	-0.18	0.10	0.07	0.08
Taiwan	4.00	10.22	0.00	0.14	1.00	0.00
Ukraine	-284.00	0.00	4.00	0.00	.	1.00
USA	-20.30	7.69	0.35	0.11	0.01	0.40

Table 2: OLS regression (quadratic) results for the panels in figures 3 and 4.

Country	α	**SE**	β	**SE**	p	β_2	**SE**	p	R^2
Australia	-78.64	113.21	2.33	3.14	0.47	-0.02	0.02	0.46	0.03
Austria	-224.95	81.94	6.26	2.30	0.02	-0.04	0.02	0.02	0.44
Belgium	48.73	25.16	-1.44	0.84	0.10	0.01	0.01	0.11	0.09
Bulgaria	474.61	315.09	-15.45	9.81	0.14	0.13	0.08	0.12	0.32
Belarus	2485.00	0.00	-70.50	0.00	.	0.50	0.00	.	1.00
Canada	6.78	49.18	-0.24	1.42	0.87	0.00	0.01	0.79	0.25
Switzerland	4.53	9.01	-0.11	0.30	0.71	0.00	0.00	0.57	0.13
Chile	79.50	0.00	0.00	0.00	.	-0.01	0.00	.	1.00
Czech Republic	-1243.82	917.97	34.81	25.72	0.21	-0.24	0.18	0.21	0.18
E Germany	-616.37	815.42	17.10	21.91	0.46	-0.12	0.15	0.45	0.20
W Germany	285.72	426.17	-7.34	11.38	0.54	0.05	0.08	0.55	0.12
Denmark	13.05	21.49	-0.36	0.74	0.63	0.00	0.01	0.58	0.02
Spain	31.40	12.53	-1.02	0.41	0.02	0.01	0.00	0.01	0.21
Estonia	-2645.14	14434.79	76.75	398.36	0.86	-0.55	2.75	0.85	0.21
Finland	8.14	18.32	-0.19	0.63	0.76	0.00	0.01	0.73	0.01
France	19.46	17.16	-0.46	0.61	0.45	0.00	0.01	0.53	0.04
Northern Ireland	35.75	68.71	-1.10	2.05	0.60	0.01	0.02	0.55	0.10
Scotland	70.98	26.89	-2.19	0.90	0.02	0.02	0.01	0.02	0.16
England & Wales	73.65	21.75	-2.27	0.72	0.00	0.02	0.01	0.00	0.23
Hungary	-1579.33	1631.50	45.45	47.36	0.37	-0.33	0.34	0.37	0.14
Ireland	-864.76	202.24	23.78	5.55	0.00	-0.16	0.04	0.00	0.65
Iceland	-9.60	16.55	0.40	0.60	0.51	-0.00	0.01	0.58	0.03
Israel	-990.38	1744.23	25.29	44.45	0.61	-0.16	0.28	0.61	0.10
Italy	3.43	5.09	-0.06	0.19	0.74	0.00	0.00	0.63	0.03
Japan	8.46	12.00	-0.36	0.36	0.32	0.00	0.00	0.15	0.69
Lithuania	21376.14	8199.30	-610.41	231.03	0.12	4.36	1.63	0.12	0.93
Luxembourg	520.03	478.83	-13.42	12.70	0.33	0.09	0.08	0.33	0.27
Latvia	-2.1e+05	0.00	5974.50	0.00	.	-41.50	0.00	.	1.00
Netherlands	65.39	19.30	-2.12	0.65	0.00	0.02	0.01	0.00	0.23
Norway	98.65	62.98	-2.88	1.96	0.15	0.02	0.02	0.16	0.08
New Zealand	-132.42	637.18	4.11	17.01	0.82	-0.03	0.11	0.80	0.20
Poland	-2441.18	1751.06	68.46	49.37	0.21	-0.48	0.35	0.22	0.28
Portugal	-12.70	23.00	0.34	0.70	0.64	-0.00	0.01	0.76	0.31
Russia									
Slovakia	-96.82	647.95	2.13	18.96	0.91	-0.01	0.14	0.95	0.20
Slovenia	-735.58	754.62	19.68	20.00	0.37	-0.13	0.13	0.37	0.18
Sweden	80.29	31.95	-2.36	1.09	0.04	0.02	0.01	0.05	0.16
Taiwan	-351.15	329.51	9.61	8.91	0.32	-0.06	0.06	0.32	0.16
Ukraine	-141.01	0.00	0.00	0.00	.	0.03	0.00	.	1.00
USA	-74.40	126.33	1.90	3.62	0.61	-0.01	0.03	0.67	0.41

coefficients are driven by outlier values, and do not represent a distinct curvilinear relationship. Explain more.

The regression results back-stop what visual inspection of figures 3 and 4 makes clear: the distinct U-shape of figure 1 is due to aggregation bias, and is not representative of the idealized path of a given country. Some countries, such as Japan and Portugal (figure 4) show believable evidence for very modest increases (as e(0) goes up) in the time required to achieve a further one-year increase in e(0). In most cases, however, there is no evidence to support the notion that increases in e(0) are harder to achieve (as evidenced by waiting times) as e(0) itself increases.

Conclusion

At the country-level, using all the available data from the Human Mortality Database, we find no systematic evidence for longer sojourn times at higher life expectancies. Overall, we interpret this as being broadly supportive of the idea that human life expectancy will continue to expand.

A few countries — most notably Portugal and Japan, and to some extent Spain — do show a small upward trend in sojourn times at more recent (i.e., larger) e(0) values. It is too early to say if this pattern will be repeated in other countries, but that would be a sign of a slowdown in the global expansion of life expectancy. Our approach is potentially more sensitive than the best-practices framework, since we look at multiple countries at a time.

The different, U-shaped, picture when the analysis is aggregated (see figure 1) is a useful reminder of the potential pitfalls of sample selection in the analysis of aggregate mortality data. This concern has been raised before (Vallin and Meslé 2010), and should spur demographers to think carefully about the limited representativeness of available high-quality mortality source data.

+More.

Notes

[1]Date accessed: 30 May 2012. We supplemented the data for France 1806–15 using Vallin and Meslé (2001), but otherwise only HMD data were used. For countries with multiple data series (for example, civilian vs total population in several countries, or Maori/non-Maori in New Zealand), we always used data for total population. In the case of East and West Germany,

we used the disaggregated series since the total population series dates from German reunification (1990–present).

[2]IDL version 8.1, Exelis Corporation, Boulder, Colorado, USA.

[3]There is an added complication at the start of each data series. Just as there is no sojourn time for hitting the target e(0)=38, the 2 year sojourn time for hitting e(0)=39 is a least upper bound, not a crisp estimate. VERIFY THAT WE DID NOT SCRUB THESE

[4]The Freedman-Diaconis (1981) rule was used for bin width determination of the histograms.

[5]The HMD is a nonrandom sample of nations and periods, so low life expectancy values in the HMD come from historical data on a select group of now-industrialized countries.

[6]Countries with data that go back that far are (start date): Belgium (1841), Switzerland (1876), Denmark(1835), Finland (1878), France(1806), Scotland (1855), England & Wales (1841), Iceland (1838), Italy (1872), The Netherlands (1850), Norway (1846), and Sweden (1751).

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