

Supporting Information for the article: Dynamics of life expectancy and lifespan equality

Authors: José Manuel Aburto^{a,b}, Francisco Villavicencio^c, Ugofilippo Basellini^{a,b,d}, Søren Kjærgaard^a & James W. Vaupel^{a,b,e}

Author affiliations:

^a Interdisciplinary Centre on Population Dynamics (CPop), University of Southern Denmark, Odense 5000, Denmark

^b Max Planck Institute for Demographic Research, Rostock 18057, Germany

^c Department of International Health, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD 21205.

^d Institut national d'études démographiques (INED), F-75020 Paris, France

^e Duke University Population Research Institute, Duke University, Durham, NC 27708.

Corresponding authors: José Manuel Aburto & James W. Vaupel
Interdisciplinary Centre on Population Dynamics (CPop), University of Southern Denmark,
Address: J.B. Winsløws Vej 9, Odense C 5000, Denmark.
Telephone: +45 65509416
JMA: jmaburto@sdu.dk
JWV: jvaupel@sdu.dk

Keywords: Aging, demography, lifespan variation, mortality, pace and shape.

Classification: Social sciences - Demography

Section A. Time series Analysis

A.1 Finding the order of integration. Formally, a stochastic process is stationary if, for every collection of time indices $1 \leq t_1 \leq \dots \leq t_m$, the joint distribution $(x_{t_1}, x_{t_2}, \dots, x_{t_m})$ is the same as the joint distribution of $(x_{t_1+h}, x_{t_2+h}, \dots, x_{t_m+h})$ (1). In loose terms, the properties of the underlying process do not change over time. In contrast, a stochastic process is integrated (i.e. non-stationary) of order d , denoted $I(d)$, if it needs to be differenced d times to achieve stationarity (2). When $d = 1$, the process has a unit root. If two variables (e.g. life expectancy and lifespan equality) are integrated and possess a unit root, then shocks are accumulated over time with growing variance, which makes statistical inference problematic (3, 4).

There are multiple tests to investigate the existence of a unit root for a stochastic process and its order of integration. Here, we used the Kwiatkowski-Phillips-Schmidt-Shin test (KPSS) (5), which tests the null hypothesis of stationarity, and the augmented Dickey-Fuller test (ADF) (6), which tests whether the process exhibits a unit root by using a parametric auto-regressive structure to capture serial correlation. The AIC information criteria is used to determine the number of lags needed. The combination of KPSS and ADF tests is common because the KPSS test reverses the null hypothesis. In addition, to make our results more robust towards structural breaks, we performed the Zivot-Andrews (7) test on the first differences of the series for all indicators used and results yielded similar conclusions.

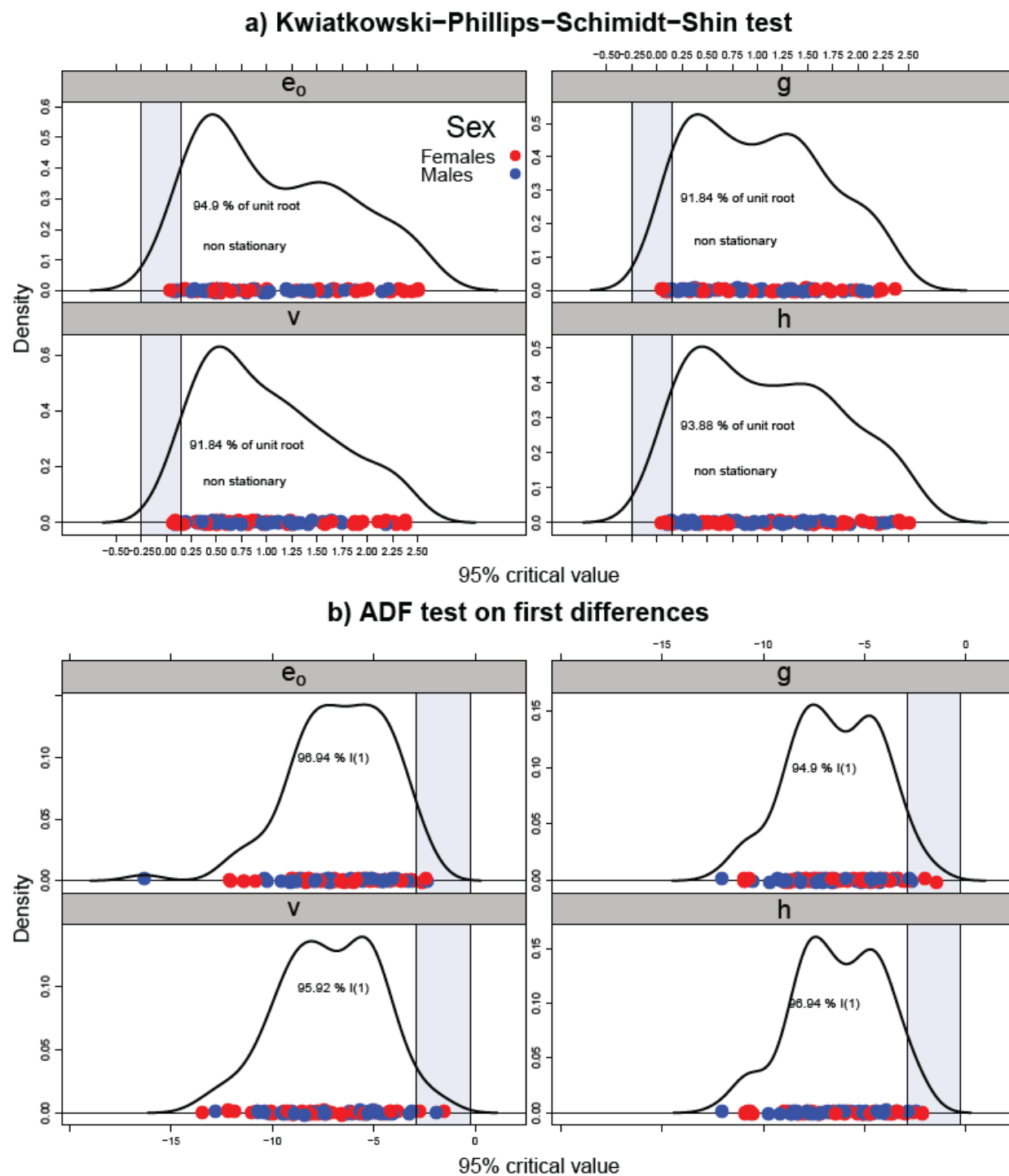
Stochastic properties of life expectancy and lifespan equality. We analyzed the stochastic properties of e_o and h over time to determine whether they are stationary processes. In case of non-stationarity, we also find the order of integration. We performed the Kwiatkowski-Phillips-Schmidt-Shin test (KPSS) (5) for e_o and h and the augmented Dickey-Fuller test (ADF) (6) in their levels and first differences, respectively.¹ Using the 95% critical values, the null hypothesis of stationarity can be rejected in 94.9% of the cases for life expectancy, and 93.9% for lifespan equality h (Fig. A1).² Moreover, at the same level, the null-hypothesis of a unit-root in their first differences is rejected 97% for e_o and almost 97% for h (see Fig. A1).³ These analyses suggest that the variables are non-stationary processes and achieve stationarity after differencing once for both females and males. For the remainder of the study, we treat both variables as integrated of order one, $I(1)$. We additionally did a consistency check in the seven countries in which KPSS and ADF showed a disagreement. These countries were Chile, South Korea, Croatia, Greece, Israel, Luxembourg and Slovenia. The first three were not considered in the cointegration analysis due to small sample size (less than 20 observations) as stated in the main manuscript. For the subsequent ADF test in the first differences, after not considering those countries that showed a disagreement, the hypothesis of non-stationarity is rejected in 100% of the cases. Therefore, we believe there is enough evidence to treat the time series as $I(1)$.

¹ We also performed tests against higher orders of integration, but could not reject the hypothesis that the variables were integrated at a lower level.

² For $g = -\ln G$ the proportion is 91.8%, and for $v = -\ln CV$ is 91.8% (see Fig. A1).

³ The corresponding values for g and v are 94.9 and 95.9%, respectively (see Fig. A1).

Fig. A1. KPSS and ADF tests for e_o , h , g and v . Calculations based on data from HMD (8)



A.2 Cointegration. The concept of cointegration was developed to avoid misleading interpretations regarding the relationship between two integrated variables (9). It refers to a model that can adjust for stochastic trends to produce stationary residuals to permit detection of stable long-run relationships among integrated variables.

Formally, two cointegrated variables can be expressed using a 2-dimensional vector autoregressive model in its equilibrium correction (VECM) form, defined as

$$\Delta z_t = \Gamma \Delta z_{t-1} + \alpha \beta' z_{t-1} + \mu + \varepsilon_t.$$

Operator Δ denoted the first difference; z_t is a 2×1 vector of stochastic variables (e_o and lifespan equality in our case) at time t ; Γ contains the cumulative long-run impacts; α and β are two 2×1 vectors of full rank, μ is a vector of constants; and ε_t is a vector of normally, independently, and identically distributed errors with zero means and constant variances. We specify the model with an unrestricted constant in the cointegration space and dummy variables in contexts where life expectancy experienced historical shocks, such as World Wars and epidemics (see Table S2). This is known as a case 4 model (3) and deals correctly with the deterministic components of the observed behavior of life expectancy and lifespan equality (10-12). An advantage of this framework is that, under cointegration, parameter estimates are super consistent, which makes them robust to omitted variables and endogeneity related issues (4).

We use the optimal lag length based on the Akaike Information Criterion (AIC). We applied four information criteria to 45 countries' time series (13-16). In all of them, the most selected lags are one and two as optimal. We decided to choose AIC in our time series analysis based on the accuracy of the method (17) to avoid over-parametrization and to have consistency across countries and sexes.

There are two test statistics for cointegration, the lambda-max and the trace statistic tests (18). The first one tests the null hypothesis of r cointegrating vectors against the specific alternative of $r + 1$ cointegrating vector(s). The trace statistic tests the null hypothesis of no cointegrating vector against a general alternative of one or more cointegrating vectors ($r > 1$). We performed both tests to each country for females and males separately. In addition, as a robustness check we used the BIC criterion to select the optimal lag length and the results were very similar. Using BIC, results yielded 90% of evidence of cointegration with the trace statistic test. Using the lambda max test, results showed 92.2% of cointegration.

Subsequently, after finding r cointegrating relationships, we estimated the VECM representation of each system. That is, we ran an ordinary least squares (OLS) regression on the lagged differenced variables and the error correction term derived from the previous step. All the analyses were carried out using the programming language R (19).

Moreover, 84% of the cases exhibit a negative error correction coefficient, which is significant in more than 60% of cases. These findings confirm that a long-run co-movement exists between life expectancy and lifespan equality. It is worth mentioning that we did not find clear patterns or jumps in the speed of adjustment and in the cointegrating vector, other than similar directions for most countries. As a robustness check we implemented the Toda and Yamamoto approach (20). In most populations under study, 79% at $p < .05$, we were able to detect Granger causality in at least one direction, but without a consistent direction. The results are that in 14 (21%) and 9 (15%) countries at $p < .05$ and $p < .1$ respectively, the null-hypothesis of no-Granger causality was not rejected in any direction between life expectancy and lifespan equality h . These countries include Greece, Ireland, Luxembourg and the Maori population of New

Zealand, populations that have been highlighted by the Human Mortality Database (HMD) as problematic in terms of data quality causing artificial fluctuations which could affect the results. Ireland, Northern Ireland, and the UK in general might be also affected by pre-census information which has also been highlighted as an issue in the HMD documentation. It should be emphasized that our main interest is on detecting cointegration rather than on interpreting the coefficients or finding causality between life expectancy and lifespan equality.

A.3 Exceptions for long-run evidence. Some populations did not show evidence of a long-run relationship: females in Lithuania, Belarus and New Zealand, and males in Lithuania, Belarus and Belgium. This could be a result of data quality and short time series. For instance, data quality is an issue in Eastern European countries from, such as Lithuania and Belarus, especially during the Soviet Period (21). New Zealand has been subject to compositional effects due to the changes in proportions of the Maori and European populations (21). Belgium was only considered for the years after 1950 because earlier gaps in the data series (21).

Section B. Time derivatives of ϑ and g

Let $\vartheta = \ell(x, t)^2 dx$, where $\ell(x, t)$ is the probability of surviving from birth to age x at time t .⁴ Applying the chain rule, its derivative with respect to time is

$$\dot{\vartheta} = \int_0^{\infty} 2\ell(x) \dot{\ell}(x) dx.$$

Using that $\dot{\ell}(x) = -\ell(x) \int_0^x \dot{\mu}(a) da$, where $\mu(a)$ is the force of mortality at age a , and reversing the order of integration, we get

$$\begin{aligned} \dot{\vartheta} &= -2 \int_0^{\infty} \ell(x)^2 \int_0^x \dot{\mu}(a) da dx = -2 \int_0^{\infty} \dot{\mu}(a) \int_a^{\infty} \ell(x)^2 dx da \\ &= 2 \int_0^{\infty} \rho(a) \mu(a) \ell(a) e(a) \frac{\int_a^{\infty} \ell(x)^2 dx}{\int_a^{\infty} \ell(a) dx} da \\ &= \int_0^{\infty} \rho(a) w(a) 2 \ell(a) \bar{\ell}(a) da. \end{aligned} \quad [\text{B1}]$$

Function $e(a)$ is the remaining life expectancy at age a , $\rho(a)$ are the rates of mortality improvement, $w(a) = \mu(a) \ell(a) e(a)$, and

$$\bar{\ell}(x) = \frac{1}{\ell(x)} \int_x^{\infty} c(a) \ell(a) da,$$

where $c(a)$ denotes the lifetable age composition.

From Eq. **2** and **8** in the main manuscript, the time derivative of the life expectancy at birth is

$$\dot{e}_o = \int_0^{\infty} w(x) \rho(x) dx, \quad [\text{B2}]$$

whereas the time derivative of $g = -\ln G$ can be expressed as

$$\dot{g} = \frac{\vartheta}{e_o - \vartheta} \left(\frac{\dot{\vartheta}}{\vartheta} - \frac{\dot{e}_o}{e_o} \right). \quad [\text{B3}]$$

Replacing Eq. **B1** and **B2** in Eq. **B3** yields

⁴ For simplicity, variable t will be omitted as an argument in the following.

$$\begin{aligned}
\dot{g} &= \frac{\vartheta}{e_o - \vartheta} \left(\frac{1}{\vartheta} \int_0^\infty \rho(x) w(x) 2\ell(x) \bar{\ell}(x) dx - \frac{1}{e_o} \int_0^\infty \rho(x) w(x) dx \right) \\
&= \int_0^\infty \rho(x) w(x) \frac{\vartheta}{e_o - \vartheta} \left(\frac{2\ell(x) \bar{\ell}(x)}{\vartheta} - \frac{1}{e_o} \right) dx \\
&= \int_0^\infty \rho(x) w(x) \frac{\vartheta}{e_o - \vartheta} \left(\frac{2\ell(x) \bar{\ell}(x)}{\vartheta} - \frac{1}{e_o} \right) dx \\
&= \int_0^\infty \rho(x) w(x) \left(\frac{2\ell(x) \bar{\ell}(x) - \bar{\ell}}{e_o - \vartheta} \right) dx \\
&= \int_0^\infty \rho(x) w(x) W_g(x) dx,
\end{aligned}$$

which provides an expression for \dot{g} that proves Eq. 9 in the main manuscript. ■

Section C. Time derivatives of σ and h

Let

$$\sigma = \sqrt{\int_0^{\infty} (x - e_o)^2 \ell(x) \mu(x) dx},$$

be the standard deviation of the lifetable age-at-death distribution. Following Gillespie *et al* (22), the time derivative of the variance of the age-at-death distribution is

$$\dot{\sigma}^2 = 2 \int_0^{\infty} \rho(x) w(x) \frac{\int_x^{\infty} \ell(a) (a - e_o) da}{e(x) \ell(x)} dx.$$

Applying the chain rule, the time derivative of σ is given by

$$\dot{\sigma} = \frac{\dot{\sigma}^2}{2\sigma} = \frac{1}{\sigma} \int_0^{\infty} \rho(x) w(x) \frac{\int_x^{\infty} \ell(a) (a - e_o) da}{e(x) \ell(x)} dx. \quad [\text{C1}]$$

On the other hand, from Eq. **11** in the main manuscript, the time derivative of $v = -\ln CV$ can be expressed as

$$\dot{v} = \frac{\dot{e}_o}{e_o} - \frac{\dot{\sigma}}{\sigma}. \quad [\text{C2}]$$

Replacing Eq. **B2** and **C1** in Eq. **C2**, we get

$$\begin{aligned} \dot{v} &= \frac{1}{e_o} \int_0^{\infty} \rho(x) w(x) dx - \frac{1}{\sigma} \int_0^{\infty} \rho(x) w(x) \frac{\int_x^{\infty} \ell(a) (a - e_o) da}{\sigma e(x) \ell(x)} dx \\ &= \int_0^{\infty} \rho(x) w(x) \left(\frac{1}{e_o} - \frac{1}{\sigma^2} \int_x^{\infty} \frac{\int_x^{\infty} \ell(a) (a - e_o) da}{\int_x^{\infty} \ell(a) da} \right) dx \\ &= \int_0^{\infty} \rho(x) w(x) \left(\frac{1}{e_o} - \frac{1}{\sigma^2} CV(x) \right) dx \\ &= \int_0^{\infty} \rho(x) w(x) W_v(x) dx. \end{aligned}$$

which provides an expression \dot{v} that proves Eq. **12** in the main manuscript. ■

Additional figures and tables

Fig. S1. Association between changes in life expectancy and changes in lifespan equality (10-year lag), g and v . Calculations based on data from HMD (8).

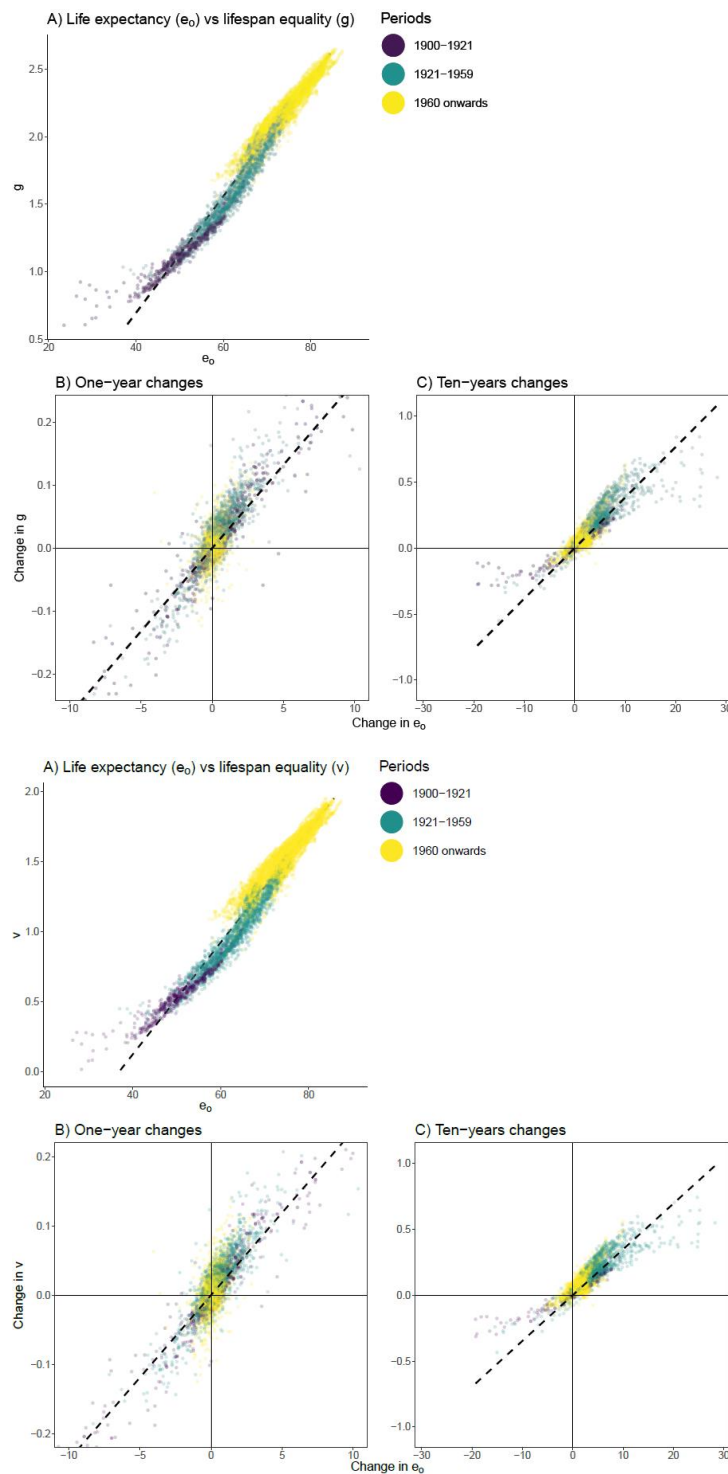


Fig. S2. Johansen Trace and Lambda Max Cointegrations tests for e_o with h , g and v . Calculations based on data from HMD (8). Since we are interested in whether e_o and h have a long-run relationship, we focus on the rejection of the null hypothesis of no long-run equilibrium. Each point indicates deviation from the 5% significance critical value. Positive values indicate a long-run relationship, while negative show no evidence to reject the null hypothesis of no long-run relationship.

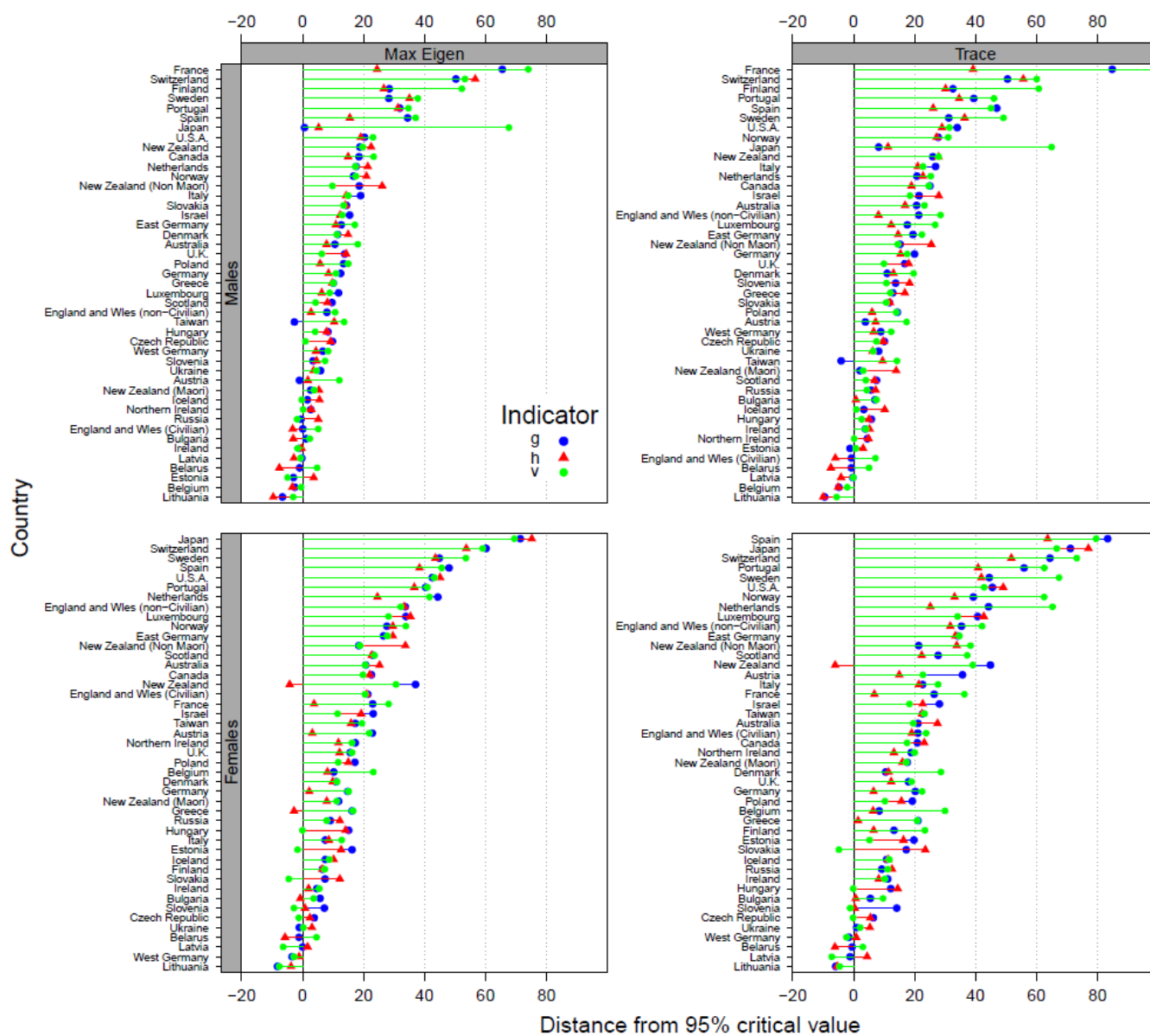


Fig. S3. Standardized weights for the changes in lifespan equality $w(x)W(x)$ for g and v .

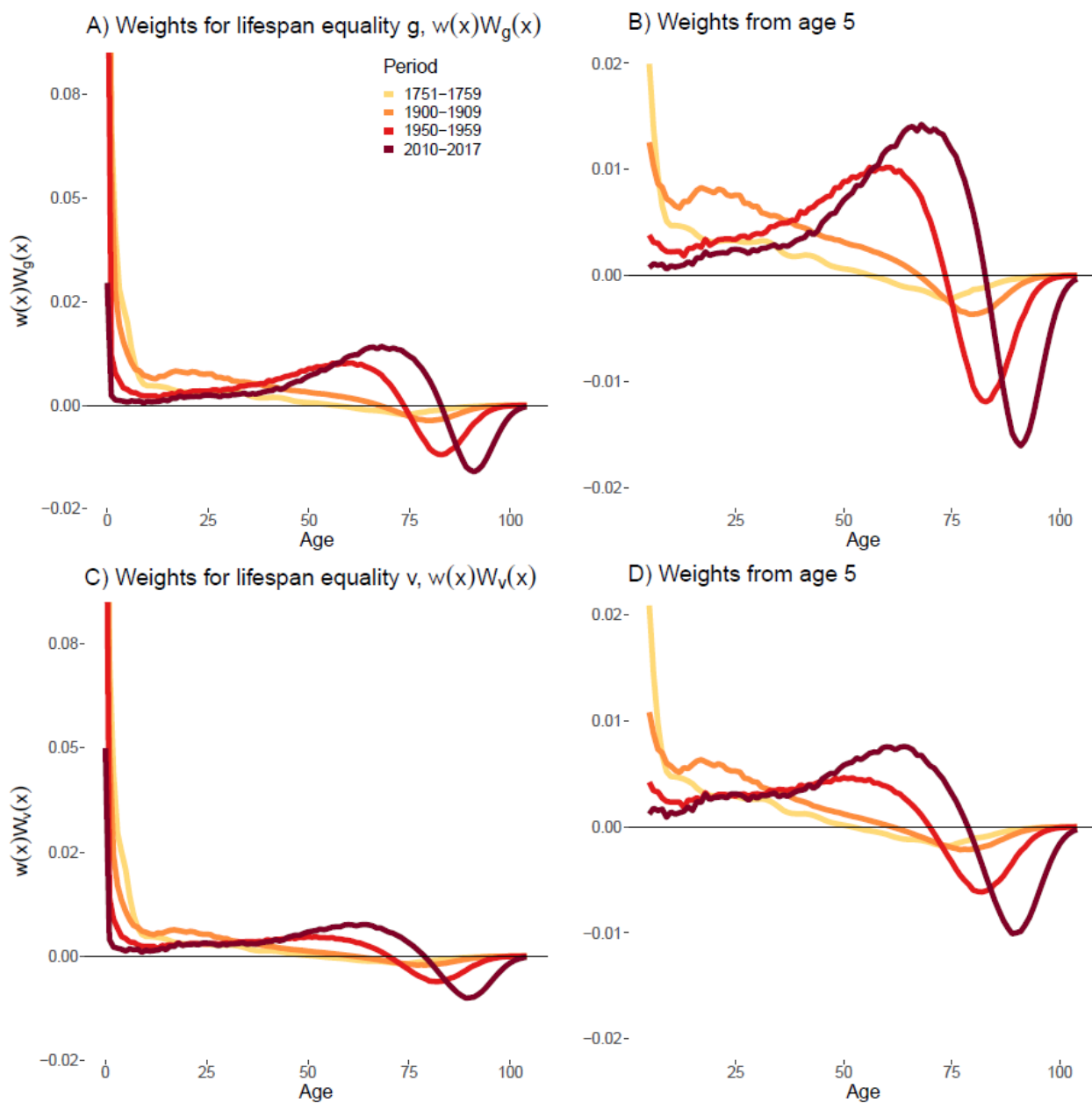


Fig. S4. Association between changes in life expectancy and lifespan equality (g and v) below and above the threshold age. Dotted lines show the directions of the relationship below and above the threshold age. Calculations based on data from HMD (8).

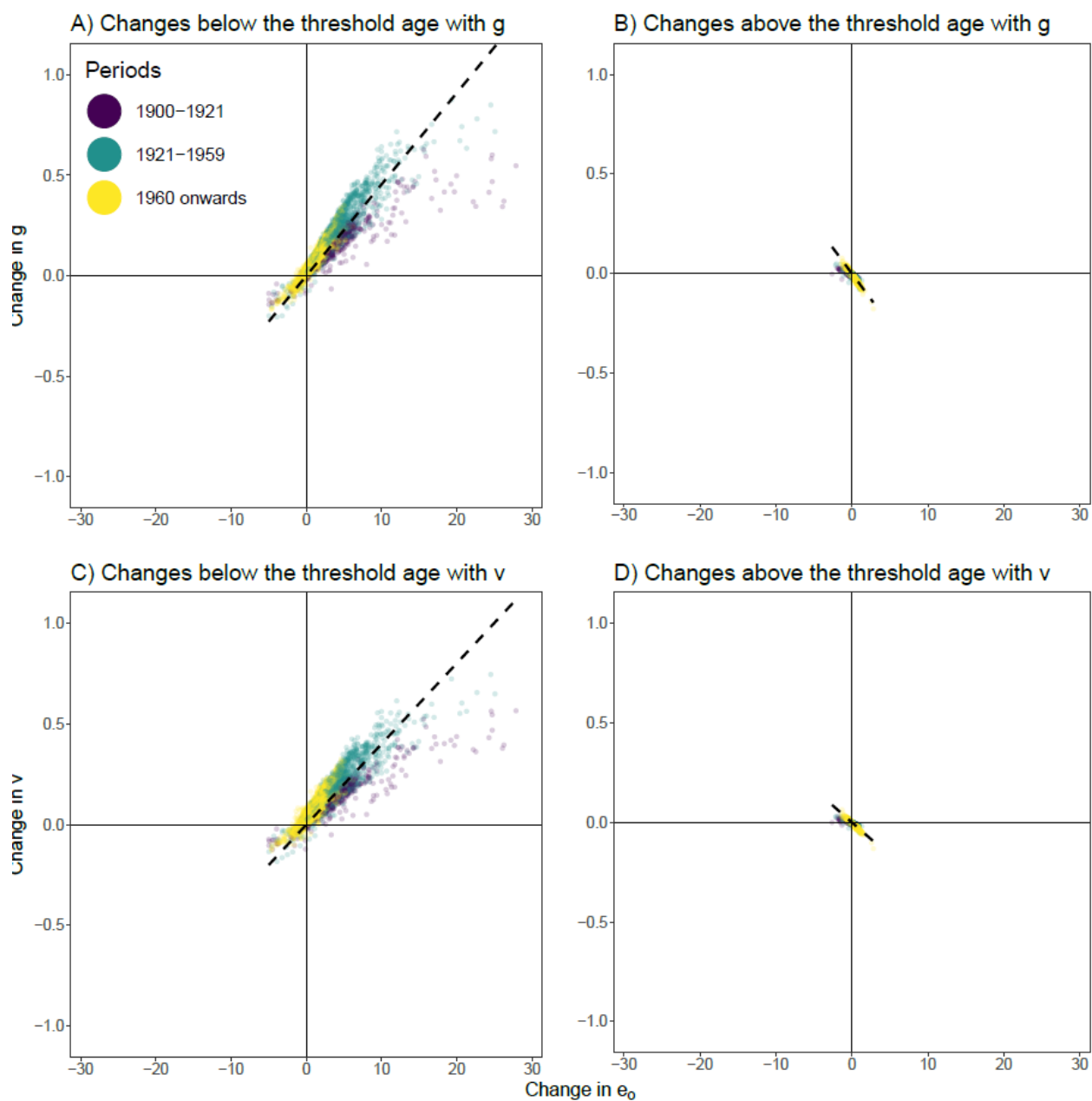


Fig. S5. Threshold age trajectories for h , g and v . Calculations based on data from HMD (8).

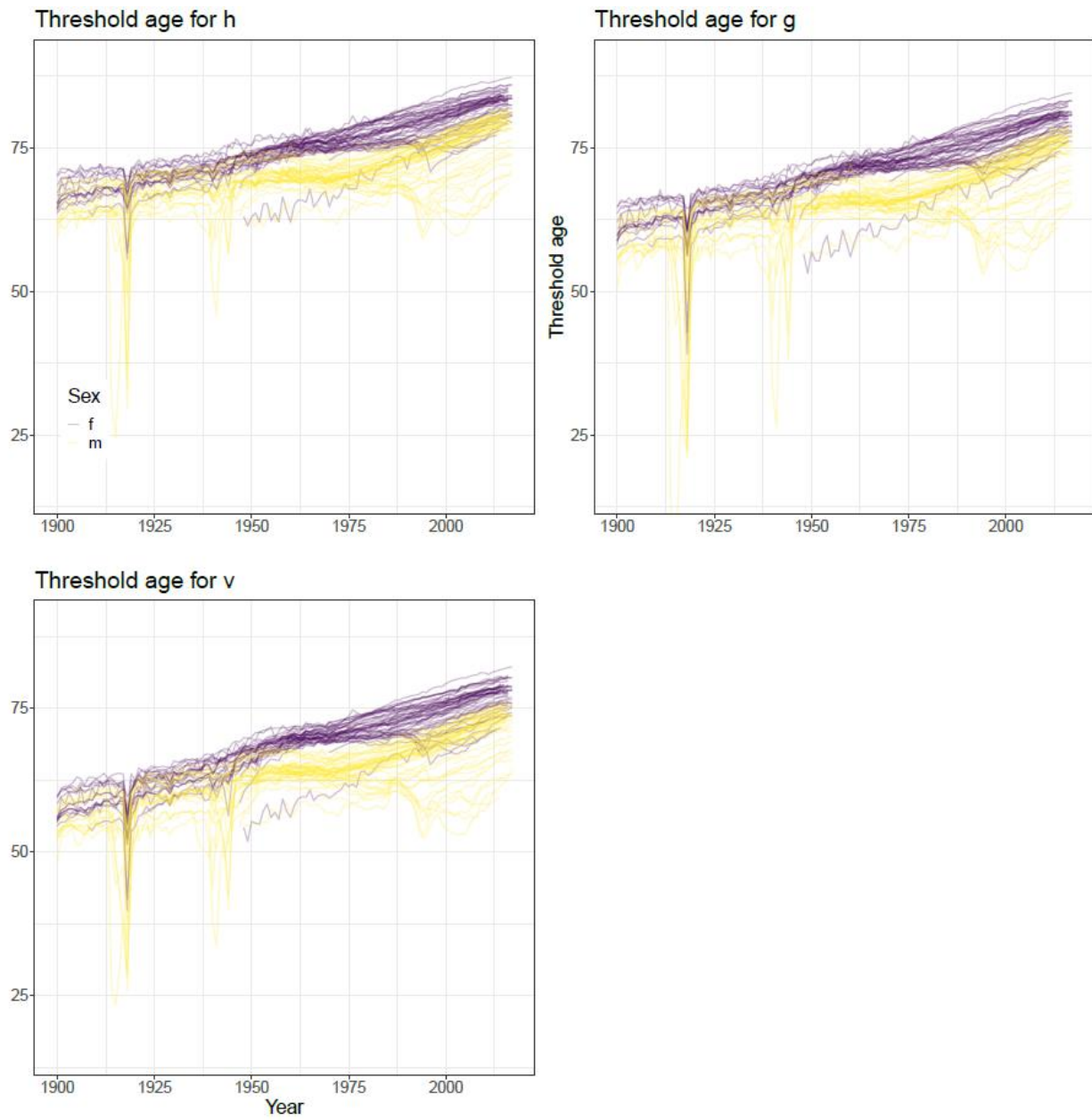


Table S1. Countries and regions in the Human Mortality Database (8) used in our study, ranked by life expectancy by sex for the latest year available.

Females										
No	Country	Initial	Final	e_o	h	g	v	α^h	α^g	α^v
1	Japan	1947	2017	87.31	2.16	2.64	1.93	87.25	84.54	82.21
2	Spain	1908	2016	85.79	2.17	2.65	1.94	85.55	82.96	80.73
3	Korea	2003	2016	85.46	2.15	2.65	1.93	84.86	82.28	80.43
4	France (civilian)	1900	2017	85.28	2.1	2.55	1.84	85.93	83.17	80.34
5	France	1900	2017	85.28	2.1	2.55	1.84	85.93	83.17	80.34
6	Switzerland	1900	2016	85.24	2.16	2.62	1.9	85.32	82.63	80.32
7	Italy	1900	2014	85.15	2.14	2.62	1.93	84.89	82.15	79.97
8	Australia	1921	2016	84.93	2.11	2.57	1.87	85.1	82.25	79.83
9	Luxembourg	1960	2014	84.49	2.09	2.57	1.87	84.34	81.35	79.21
10	Israel	1983	2016	84.24	2.11	2.59	1.89	83.92	81.05	79.03
11	Finland	1900	2015	84.19	2.14	2.6	1.91	84.18	81.41	79.04
12	Canada	1921	2016	84.18	1.99	2.46	1.77	84.69	81.34	78.81
13	Sweden	1900	2017	84.12	2.13	2.6	1.91	84.03	81.13	78.89
14	Norway	1900	2014	84.1	2.11	2.59	1.91	84.00	81.07	78.76
15	Portugal	1940	2015	84.03	2.16	2.63	1.92	84.00	81.38	79.11
16	Austria	1947	2017	83.89	2.14	2.6	1.9	84.06	81.31	78.83
17	Iceland	1900	2016	83.88	2.13	2.61	1.96	83.51	80.34	78.23
18	Slovenia	1983	2017	83.68	2.12	2.59	1.9	83.64	80.89	78.51
19	Greece	1981	2013	83.67	2.11	2.6	1.89	83.14	80.6	78.6
20	New Zealand	1948	2013	83.43	2.04	2.5	1.79	83.88	80.84	78.31
21	East Germany	1956	2017	83.32	2.1	2.56	1.87	83.5	80.67	78.16
22	Germany	1990	2017	83.29	2.1	2.56	1.86	83.56	80.69	78.14
23	West Germany	1956	2017	83.28	2.1	2.55	1.86	83.57	80.7	78.14
24	Ireland	1950	2014	83.21	2.05	2.54	1.84	82.95	80.03	77.89

25	Belgium	1919	2015	83.15	2.07	2.52	1.83	83.65	80.69	78.02
26	Netherlands	1900	2016	83.12	2.08	2.54	1.85	83.48	80.53	77.95
27	New Zealand (Non Maori)	1901	2008	83.06	2.06	2.52	1.81	83.31	80.32	77.98
28	England and Wales (Civilian)	1900	2016	83.04	2.03	2.5	1.81	83.25	80.13	77.71
29	England and Wales (non-Civilian)	1900	2016	83.04	2.03	2.5	1.81	83.25	80.13	77.71
30	U.K.	1922	2016	82.84	2.02	2.49	1.8	83.07	79.91	77.49
31	Taiwan	1970	2014	82.82	1.99	2.47	1.78	82.75	79.53	77.40
32	Denmark	1900	2016	82.79	2.03	2.51	1.84	82.7	79.47	77.21
33	Northern Ireland	1922	2016	82.3	1.99	2.46	1.76	82.58	79.37	77.00
34	Estonia	1959	2017	82.29	2.03	2.5	1.83	82.4	79.4	76.96
35	Czech Republic	1950	2017	81.86	2.09	2.55	1.88	81.85	78.86	76.53
36	Poland	1958	2016	81.72	1.99	2.45	1.78	82.02	78.72	76.22
37	U.S.A.	1933	2017	81.39	1.86	2.31	1.64	82.45	78.67	75.96
38	Chile	1992	2008	81.13	1.92	2.39	1.69	81.34	78.07	75.96
39	Scotland	1900	2016	81.06	1.95	2.41	1.74	81.46	78.03	75.57
40	Croatia	2002	2017	80.86	2.08	2.55	1.85	80.72	77.9	75.74
41	Slovakia	1950	2017	80.57	2.01	2.48	1.79	80.56	77.59	75.32
42	Lithuania	1959	2017	80.37	1.98	2.42	1.74	81.19	78.00	75.14
43	Latvia	1959	2017	79.53	1.93	2.37	1.7	80.51	77.02	74.22
44	Hungary	1950	2017	79.27	1.94	2.41	1.76	79.37	75.99	73.6
45	Belarus	1959	2016	79.02	1.95	2.41	1.74	79.2	76.00	73.62
46	Bulgaria	1947	2010	77.25	1.93	2.36	1.64	78.13	75.09	72.66
47	Russia	1959	2014	76.48	1.79	2.21	1.54	78.07	74.41	71.48
48	Ukraine	1959	2013	76.2	1.82	2.27	1.59	77.11	73.58	71.14
49	New Zealand (Maori)	1948	2008	75.64	1.72	2.21	1.57	75.95	71.02	69.34

Males

No	Country	Initial	Final	e_o	h	g	v	α^h	α^g	α^v
50	Switzerland	1900	2016	81.53	2.03	2.49	1.81	81.9	78.75	76.26
51	Japan	1947	2017	81.13	1.97	2.44	1.78	81.36	77.95	75.52
52	Australia	1921	2016	80.83	1.94	2.39	1.71	81.5	78.17	75.55
53	Sweden	1900	2017	80.73	2.03	2.47	1.79	81.2	78.07	75.56
54	Israel	1983	2016	80.65	1.91	2.39	1.73	80.62	77.05	74.93
55	Italy	1900	2014	80.55	1.99	2.46	1.78	80.67	77.38	75.08
56	Iceland	1900	2016	80.3	2.04	2.48	1.79	80.76	77.78	75.25
57	Spain	1908	2016	80.27	1.94	2.41	1.76	80.51	76.9	74.52
58	Canada	1921	2016	80.05	1.88	2.32	1.65	81.04	77.32	74.68
59	Norway	1900	2014	80.03	1.99	2.44	1.76	80.36	77.05	74.69
60	Netherlands	1900	2016	79.88	2.00	2.46	1.78	79.99	76.75	74.53
61	New Zealand	1948	2013	79.8	1.91	2.36	1.67	80.41	77.07	74.63
62	France (civilian)	1900	2017	79.44	1.88	2.31	1.65	80.91	77.03	73.92
63	France	1900	2017	79.44	1.88	2.31	1.65	80.91	77.03	73.92
64	England and Wales (Civilian)	1900	2016	79.42	1.91	2.36	1.69	80.01	76.44	73.99
65	England and Wales (non-Civilian)	1900	2016	79.42	1.91	2.36	1.69	80.01	76.44	73.99
66	Korea	2003	2016	79.34	1.92	2.4	1.73	79.37	76.09	73.84
67	Austria	1947	2017	79.28	1.94	2.39	1.73	79.85	76.14	73.68
68	U.K.	1922	2016	79.18	1.9	2.35	1.68	79.82	76.22	73.74
69	Ireland	1950	2014	79.16	1.91	2.38	1.69	79.43	76.16	73.84
70	Luxembourg	1960	2014	79.13	1.96	2.4	1.74	79.78	76.06	73.54
71	New Zealand (Non Maori)	1901	2008	79.05	1.89	2.35	1.66	79.44	76.21	74.00
72	Denmark	1900	2016	78.95	1.93	2.39	1.73	79.39	75.78	73.34
73	West Germany	1956	2017	78.81	1.93	2.39	1.73	79.35	75.62	73.19
74	Northern Ireland	1922	2016	78.76	1.88	2.32	1.65	79.6	75.96	73.42
75	Finland	1900	2015	78.62	1.9	2.35	1.71	79.34	75.54	72.94
76	Belgium	1919	2015	78.57	1.91	2.35	1.70	79.23	75.47	72.99
77	Germany	1990	2017	78.56	1.92	2.37	1.72	79.15	75.35	72.87
78	Greece	1981	2013	78.45	1.82	2.3	1.65	78.89	75.11	72.65
79	Slovenia	1983	2017	78.08	1.92	2.38	1.74	78.29	74.56	72.23

80	Portugal	1940	2015	78.02	1.89	2.33	1.68	79.11	75.39	72.55
81	East Germany	1956	2017	77.66	1.87	2.32	1.69	78.38	74.29	71.73
82	Scotland	1900	2016	76.93	1.8	2.25	1.6	77.99	74.01	71.35
83	Taiwan	1970	2014	76.54	1.72	2.19	1.55	77.4	73.26	70.74
84	U.S.A.	1933	2017	76.35	1.68	2.12	1.47	78.31	73.82	70.94
85	Czech Republic	1950	2017	76.01	1.85	2.31	1.67	76.21	72.01	70.08
86	Chile	1992	2008	75.33	1.72	2.18	1.51	76.25	72.36	70.14
87	Croatia	2002	2017	74.87	1.82	2.28	1.64	75.15	71.00	69.05
88	Poland	1958	2016	73.84	1.68	2.15	1.53	74.25	69.32	67.53
89	Slovakia	1950	2017	73.76	1.73	2.21	1.57	73.84	69.44	67.72
90	Estonia	1959	2017	73.66	1.71	2.18	1.56	73.82	69.01	67.34
91	Hungary	1950	2017	72.56	1.71	2.21	1.6	71.95	67.11	65.94
92	New Zealand (Maori)	1948	2008	72.51	1.49	2.07	1.44	72.1	67.55	66.19
93	Lithuania	1959	2017	70.7	1.61	2.07	1.46	71.37	66.14	64.39
94	Bulgaria	1947	2010	70.31	1.65	2.09	1.44	71.48	66.76	64.91
95	Latvia	1959	2017	69.8	1.58	2.04	1.44	70.3	65.1	63.5
96	Belarus	1959	2016	68.96	1.6	2.09	1.49	68.73	63.91	62.57
97	Ukraine	1959	2013	66.31	1.47	1.94	1.33	67.16	61.84	60.34
98	Russia	1959	2014	65.26	1.38	1.85	1.26	66.95	61.08	59.38

Table S2. Years in which dummy variables were added. The dummy variables account for the following historic events: 1918 the Spanish flu, 1914-1919 World War 1, 1940-1945 World War II (1939 included for Spain to account for the Spanish civil war) and 1992-1995 dissolution of the Soviet Union.

Country	Data years	Dummy Years
Australia	1921 – 2016	None
Austria	1947 – 2017	None
Belgium	1920 – 2015	1940 - 1945
Bulgaria	1947 – 2010	None
Belarus	1959 – 2016	1992 - 1995
Canada	1921 – 2016	None
Czech Republic	1950 – 2017	None
Denmark	1900 – 2016	1918 and 1940 - 1945
Estonia	1959 – 2017	1992 - 1995
Finland	1900 – 2015	1918 and 1940 - 1945
France	1900 – 2017	1914 - 1919 and 1940 -1945
Germany	1990 – 2017	None
Greece	1981 – 2013	None
Hungary	1950 – 2017	1992 - 1995
Iceland	1900 – 2016	None
Ireland	1950 – 2014	None
Israel	1983 – 2016	None
Italy	1900 – 2014	1914 - 1919 and 1940 - 1945
East Germany	1956 – 2017	1992 - 1995
West Germany	1956 – 2017	None
Japan	1947 – 2017	None
Latvia	1959 – 2017	1992 - 1995
Lithuania	1959 – 2017	1992 - 1995
Luxembourg	1960 – 2014	None
Netherlands	1900 – 2016	1918 and 1940 - 1945
New Zealand Maori	1948 – 2008	1918
New Zealand Non-Maori	1948 – 2008	1918
Norway	1900 – 2014	1918 and 1940 - 1945
Northern Ireland	1922 – 2016	1940 - 1945
Poland	1958 – 2016	1992 - 1995
Portugal	1940 – 2015	None
Russia	1959 – 2014	1992 - 1995
Scotland	1900 – 2016	None
Slovakia	1950 – 2017	None
Slovenia	1983 – 2017	None
Spain	1908 – 2016	1918 and 1939 - 1945
Sweden	1900 – 2017	1918
Switzerland	1900 – 2016	1918
Taiwan	1970 - 2014	None
Ukraine	1959 - 2013	1992 - 1995
UK	1922 - 2016	1940 - 1945

References

1. J. M. Wooldridge, *Introductory econometrics: A modern approach* (Nelson Education, 2015).
2. J. M. Wooldridge, Estimation and inference for dependent processes. *Handbook of econometrics* **4**, 2639-2738 (1994).
3. K. Juselius, *The cointegrated VAR model: methodology and applications* (Oxford University Press, 2006).
4. B. Pfaff, *Analysis of integrated and cointegrated time series with R* (Springer Science & Business Media, 2008).
5. D. Kwiatkowski, P. C. Phillips, P. Schmidt, Y. Shin, Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? *Journal of Econometrics* **54**, 159-178 (1992).
6. D. A. Dickey, W. A. Fuller, Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* **74**, 427-431 (1979).
7. E. Zivot, D. W. K. Andrews, Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *Journal of business & economic statistics* **20**, 25-44 (2002).
8. University of California Berkeley and Max Planck Institute for Demographic Research (Germany) (2019) Human Mortality Database (<https://www.mortality.org/>).
9. C. W. Granger, Some properties of time series data and their use in econometric model specification. *Journal of Econometrics* **16**, 121-130 (1981).
10. F. W. Ahking, Model mis-specification and Johansen's co-integration analysis: an application to the US money demand. *Journal of Macroeconomics* **24**, 51-66 (2002).
11. J. A. Doornik, Approximations to the asymptotic distributions of cointegration tests. *Journal of Economic Surveys* **12**, 573-593 (1998).
12. M. Osterwald-Lenum, A note with quantiles of the asymptotic distribution of the maximum likelihood cointegration rank test statistics1. *Oxford Bulletin of Economics and statistics* **54**, 461-472 (1992).
13. H. Akaike, Likelihood of a model and information criteria. *Journal of econometrics* **16**, 3-14 (1981).
14. E. J. Hannan, B. G. Quinn, The determination of the order of an autoregression. *Journal of the Royal Statistical Society. Series B (Methodological)*, 190-195 (1979).
15. H. Lütkepohl, *New introduction to multiple time series analysis* (Springer Science & Business Media, 2005).
16. G. Schwarz, others, Estimating the dimension of a model. *The annals of statistics* **6**, 461-464 (1978).
17. V. Ivanov, L. Kilian, A practitioner's guide to lag order selection for VAR impulse response analysis. *Studies in Nonlinear Dynamics and Econometrics* **9**, 1-34 (2005).
18. S. r. Johansen, The role of the constant and linear terms in cointegration analysis of nonstationary variables. *Econometric reviews* **13**, 205-229 (1994).
19. R. Ihaka, R. Gentleman, R: a language for data analysis and graphics. *Journal of computational and graphical statistics* **5**, 299-314 (1996).
20. H. Y. Toda, T. Yamamoto, Statistical inference in vector autoregressions with possibly integrated processes. *Journal of econometrics* **66**, 225-250 (1995).
21. B. U. Human Mortality Database. University of California, and Max Planck Institute for Demographic Research (Germany), Human Mortality Database.

22. D. O. Gillespie, M. V. Trotter, S. D. Tuljapurkar, Divergence in age patterns of mortality change drives international divergence in lifespan inequality. *Demography* **51**, 1003-1017 (2014).