

1

2 **Supplementary Information for**

3 **An Advancing Front of Old Age Human Survival**

4 **Wenyun Zuo¹⁺, Sha Jiang^{2,1+}, Zhen Guo², Marcus W. Feldman¹, Shripad Tuljapurkar^{1*}**

5 ¹Department of Biology, Stanford University, Stanford, CA 94040, USA,

6 ²School of Sociology, Huazhong University of Science and Technology, Wuhan, 430074, P.R.China

7 ⁺These authors contributed equally to this work.

8 *Corresponding Author: Shripad Tuljapurkar

9 E-mail: tulja@stanford.edu

10 **This PDF file includes:**

11 Figs. S1 to S14

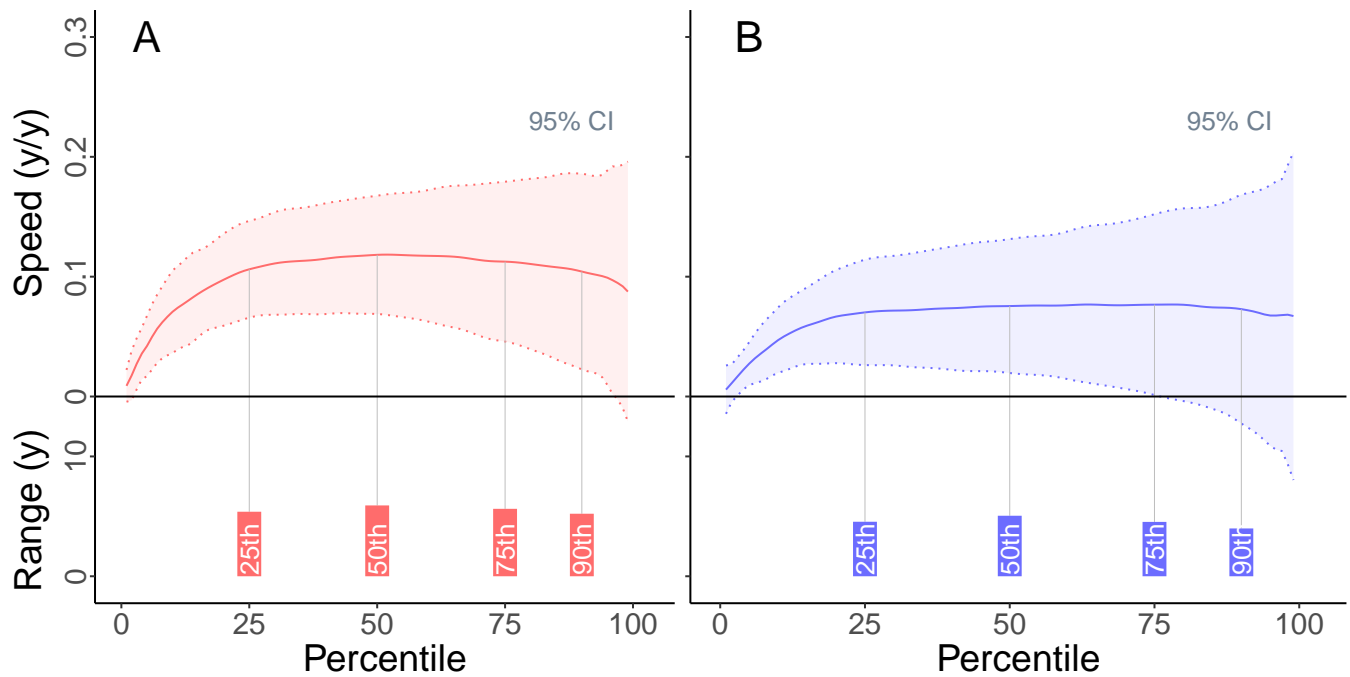


Fig. S1. For Netherlands. **A** and **B.** Speeds (rates of movement) for percentiles A_q at every 1% (using raw data on death ages above A_{90}). Top, speeds for percentiles for females on left, respectively males on right. Solid line (red, respectively blue) indicates long-term speed. Percentiles from the 25th to the 90th show similar long-term speeds (note the vertical scale). Long-term speeds ≈ 0.2 y/y for females. Also shown: the 95% confidence interval ($1.96 \times \text{SD}$, distributions symmetric and approximately normal) for annual speeds: dotted lines and bands (pink, respectively blue). Annual variability is high (compare modest annual variability for intervals between percentiles, examples are in Fig. 1C and D). Bottom panels, solid bars (red, females, blue, males) show ranges. For clarity and economy of space, we show only 4 countries including this one.

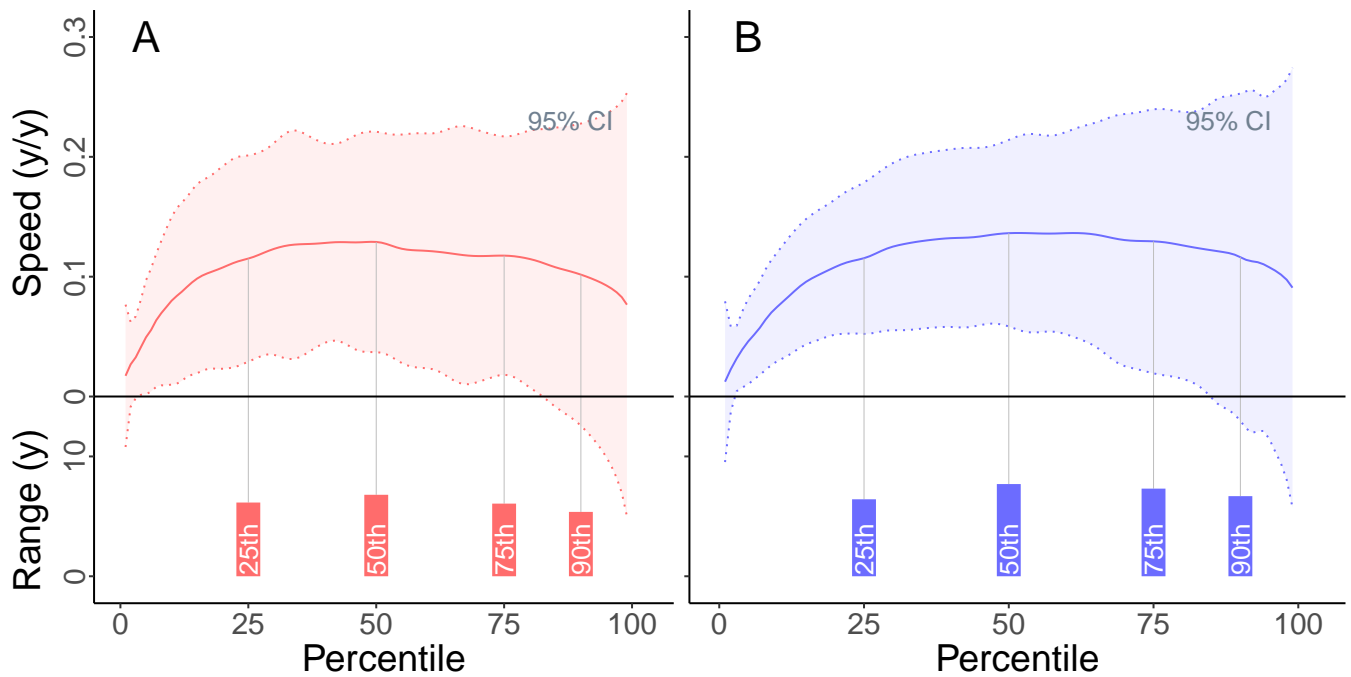


Fig. S2. For New Zealand. **A** and **B.** Speeds (rates of movement) for percentiles A_q at every 1% (using raw data on death ages above A_{90}). Top, speeds for percentiles for females on left, respectively males on right. Solid line (red, respectively blue) indicates long-term speed. Percentiles from the 25th to the 90th show similar long-term speeds (note the vertical scale). Long-term speeds ≈ 0.2 y/y for females. Also shown: the 95% confidence interval ($1.96 \times \text{SD}$, distributions symmetric and approximately normal) for annual speeds: dotted lines and bands (pink, respectively blue). Annual variability is high (compare modest annual variability for intervals between percentiles, examples are in Fig. 1C and D). Bottom panels, solid bars (red, females, blue, males) show ranges. For clarity and economy of space, we show only 4 countries including this one.

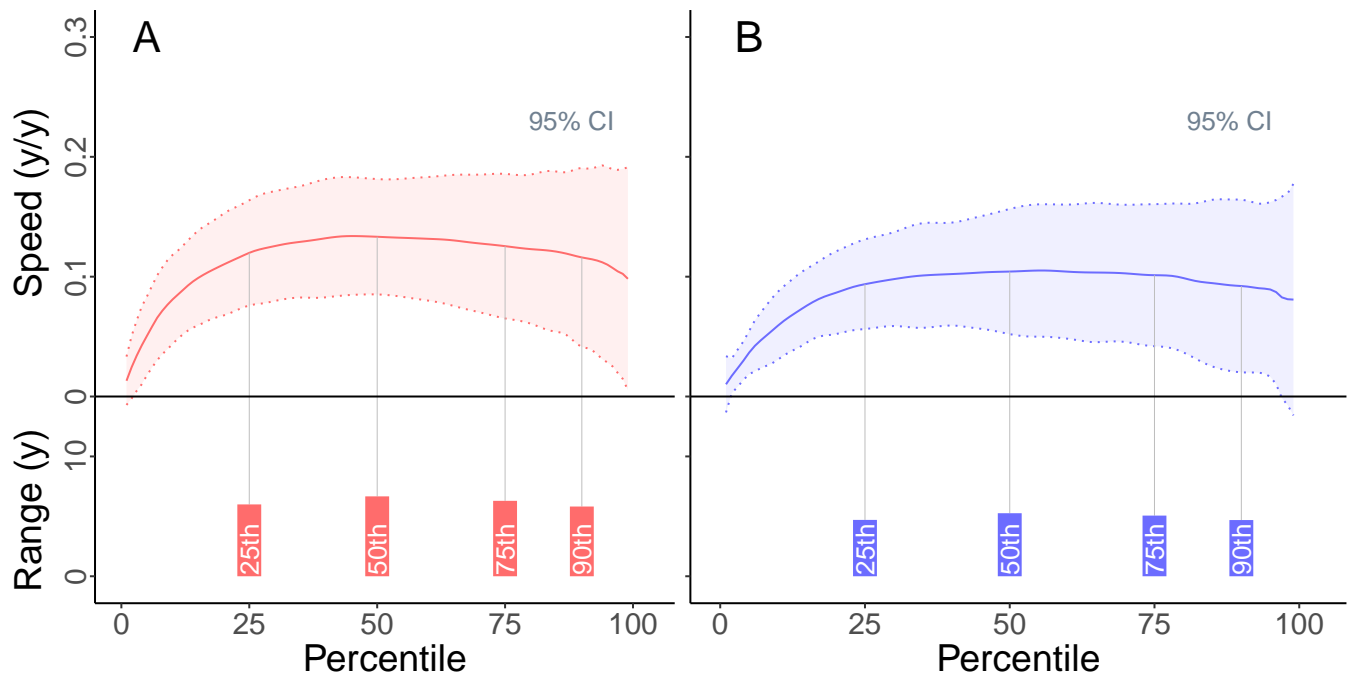


Fig. S3. For Sweden. **A** and **B.** Speeds (rates of movement) for percentiles A_{90} at every 1% (using raw data on death ages above A_{90}). Top, speeds for percentiles for females on left, respectively males on right. Solid line (red, respectively blue) indicates long-term speed. Percentiles from the 25th to the 90th show similar long-term speeds (note the vertical scale). Long-term speeds ≈ 0.2 y/y for females. Also shown: the 95% confidence interval ($1.96 \times \text{SD}$, distributions symmetric and approximately normal) for annual speeds: dotted lines and bands (pink, respectively blue). Annual variability is high (compare modest annual variability for intervals between percentiles, Fig. 1C and D). Bottom panels, solid bars (red, females, blue, males) show ranges. For clarity and economy of space, we show only 4 countries including this one.

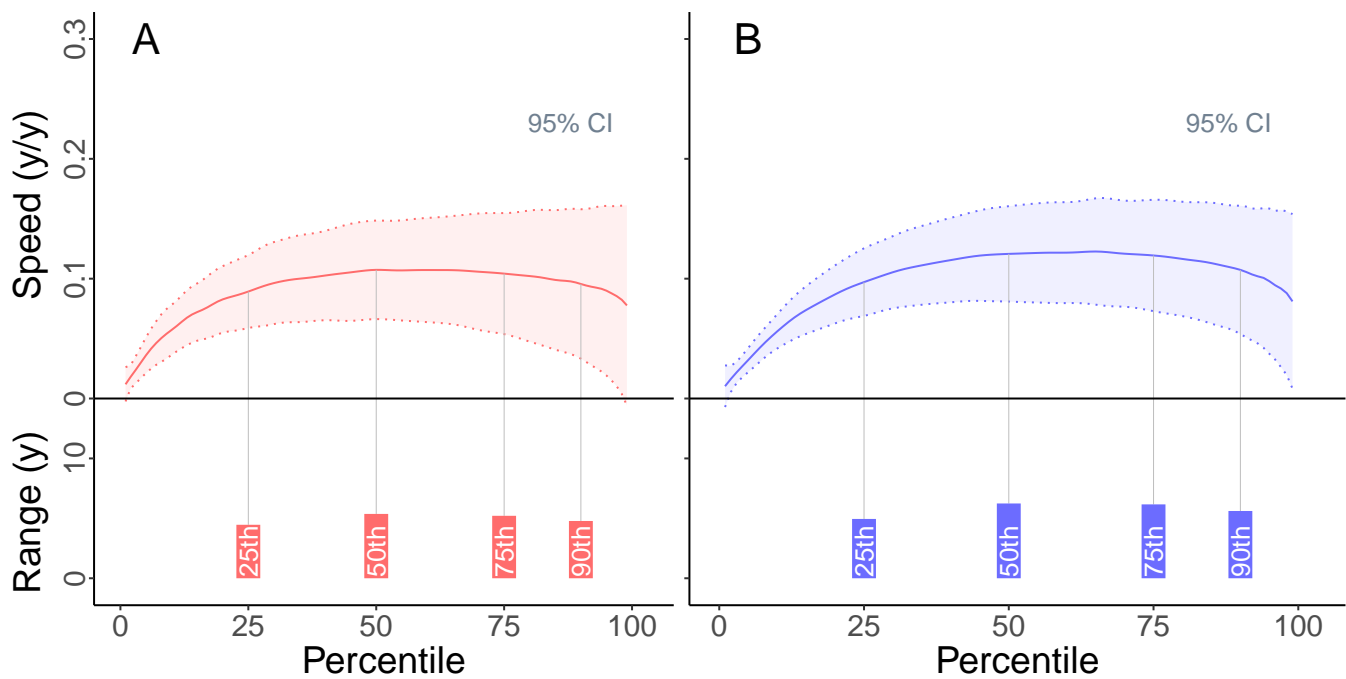


Fig. S4. For The United States. **A** and **B.** Speeds (rates of movement) for percentiles A_q at every 1% (using raw data on death ages above A_{90}). Top, speeds for percentiles for females on left, respectively males on right. Solid line (red, respectively blue) indicates long-term speed. Percentiles from the 25th to the 90th show similar long-term speeds (note the vertical scale). Long-term speeds ≈ 0.2 y/y for females. Also shown: the 95% confidence interval ($1.96 \times \text{SD}$, distributions symmetric and approximately normal) for annual speeds: dotted lines and bands (pink, respectively blue). Annual variability is high (compare modest annual variability for intervals between percentiles, Fig. 1C and D). Bottom panels, solid bars (red, females, blue, males) show ranges. For clarity and economy of space, we show only 4 countries including this one.

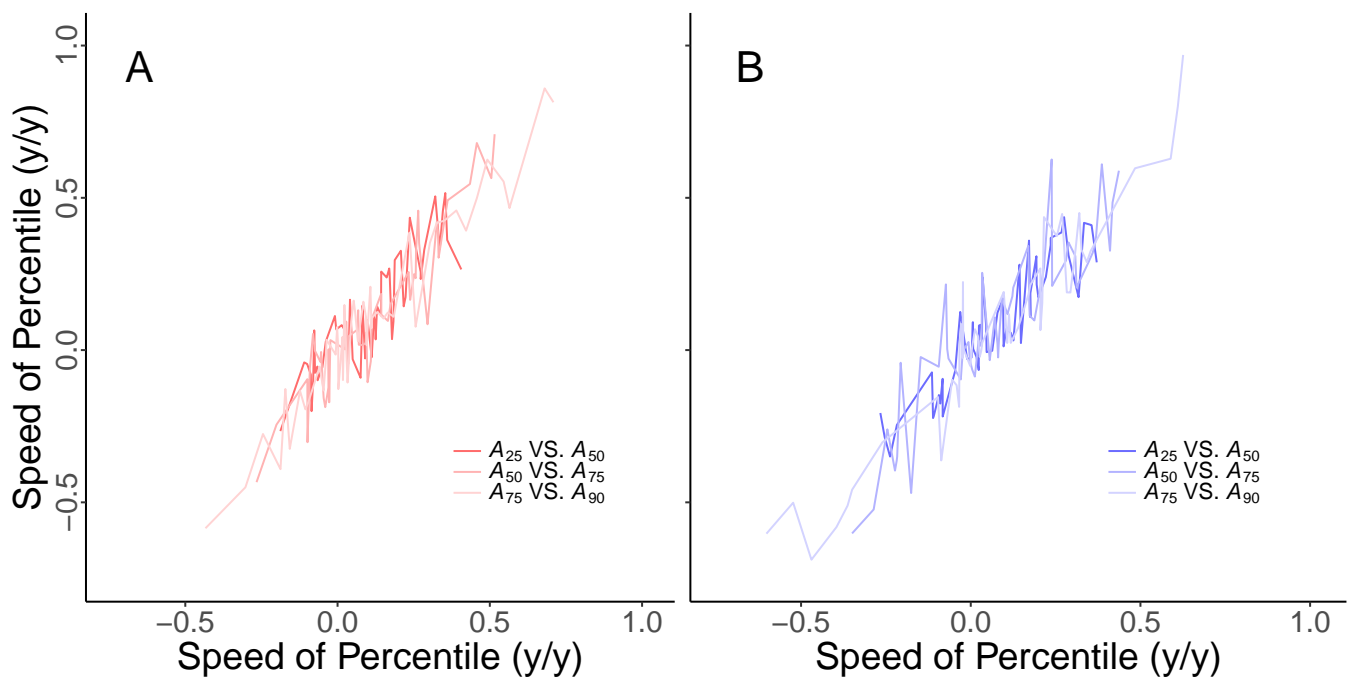


Fig. S5. For Netherlands, for each ending year, annual speeds of the percentiles: e.g., annual change in A_{50} on the vertical versus annual change in A_{25} on the horizontal, and correspondingly for the pairs A_{75} , A_{50} and A_{90} , A_{75} . left panel **A** for females, right panel **B** for males). For clarity and economy of space, we show only 4 countries including this one.

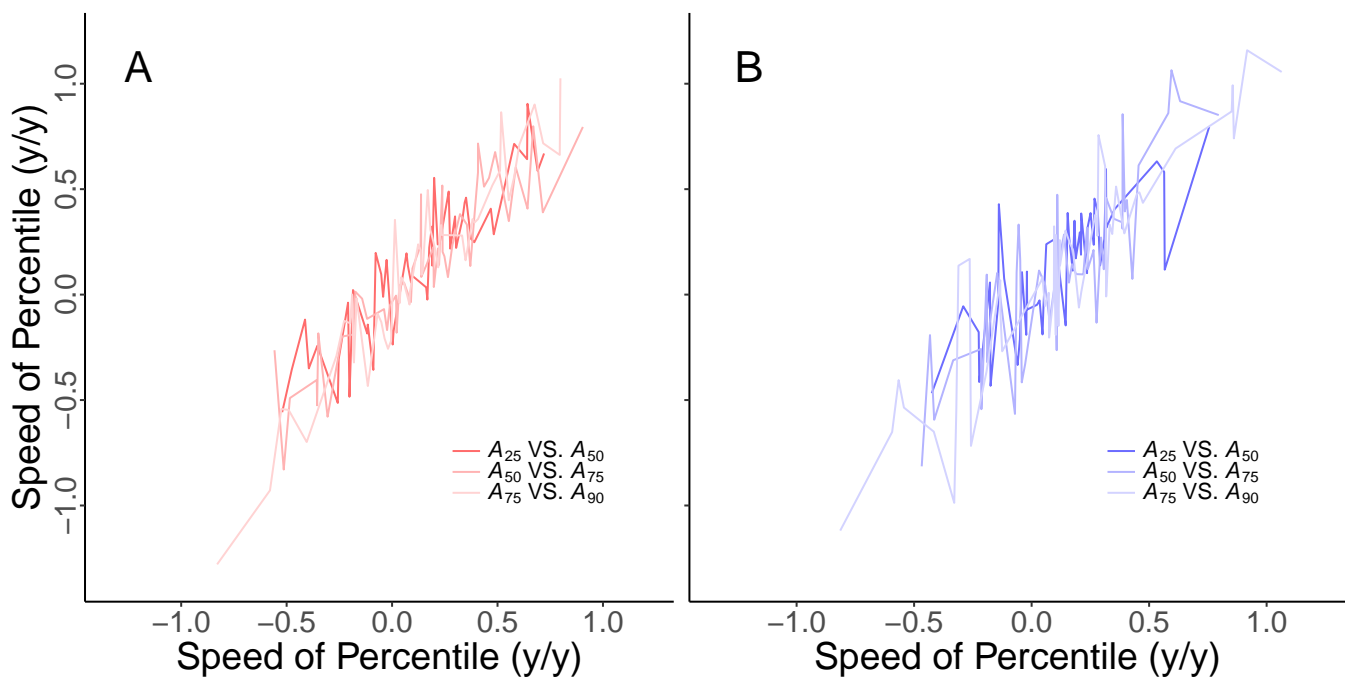


Fig. S6. For New Zealand, for each ending year, annual speeds of the percentiles: e.g., annual change in A_{50} on the vertical versus annual change in A_{25} on the horizontal, and correspondingly for the pairs A_{75}, A_{50} and A_{90}, A_{75} . left panel **A** for females, right panel **B** for males). For clarity and economy of space, we show only 4 countries including this one.

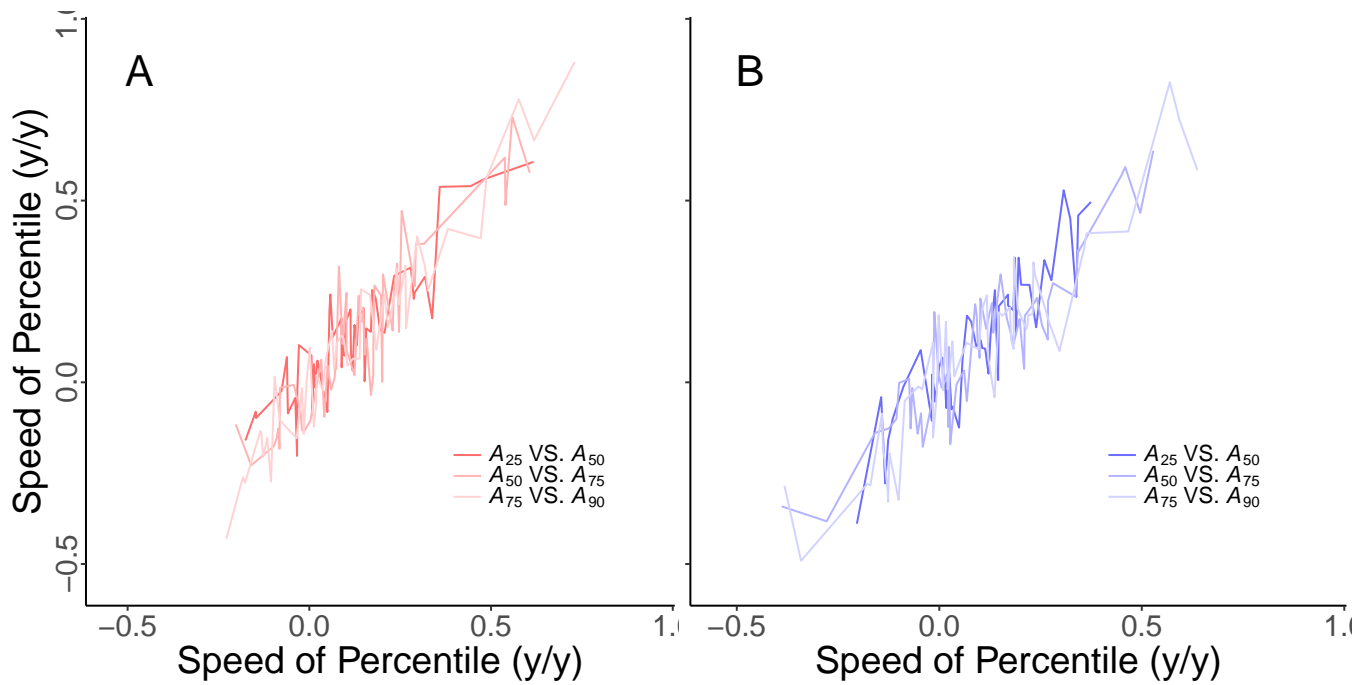


Fig. S7. For Sweden, for each ending year, annual speeds of the percentiles: e.g., annual change in A_{50} on the vertical versus annual change in A_{25} on the horizontal, and correspondingly for the pairs A_{75}, A_{50} and A_{90}, A_{75} . left panel **A** for females, right panel **B** for males). For clarity and economy of space, we show only 4 countries including this one.

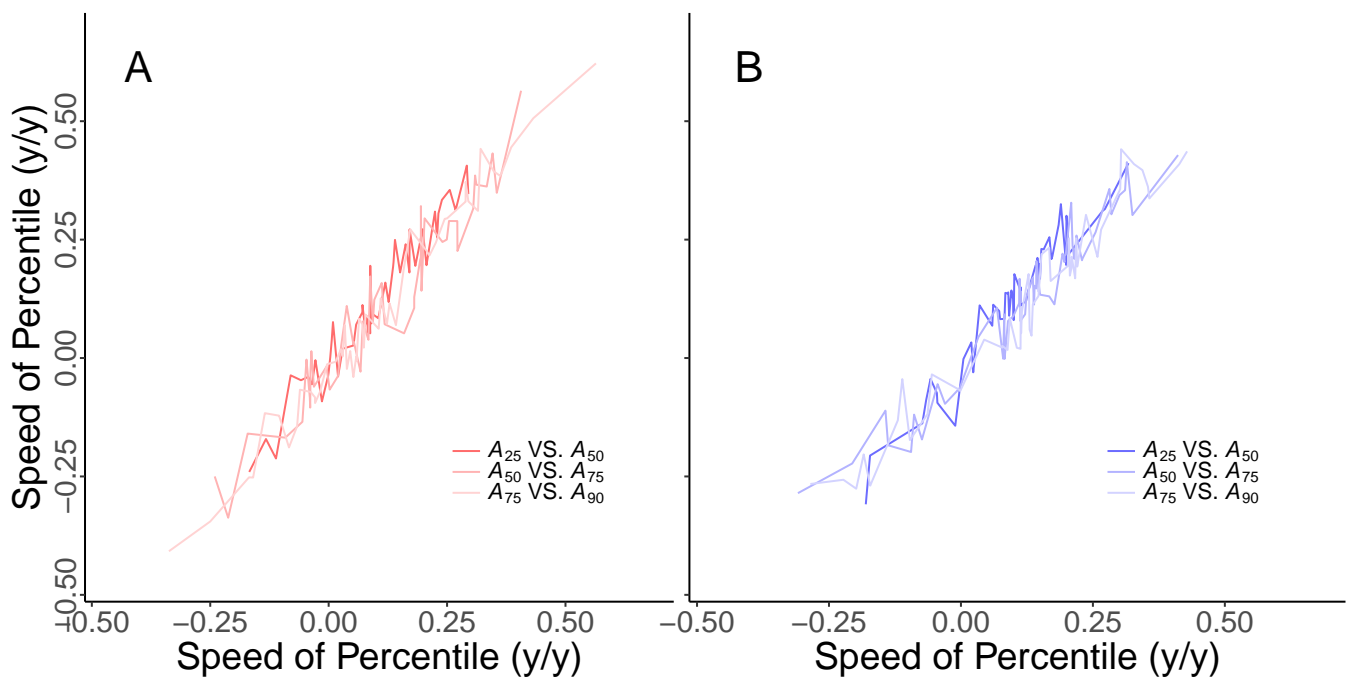


Fig. S8. For the US, for each ending year, annual speeds of the percentiles: e.g., annual change in A_{50} on the vertical versus annual change in A_{25} on the horizontal, and correspondingly for the pairs A_{75}, A_{50} and A_{90}, A_{75} . left panel **A** for females, right panel **B** for males). For clarity and economy of space, we show only 4 countries including this one.

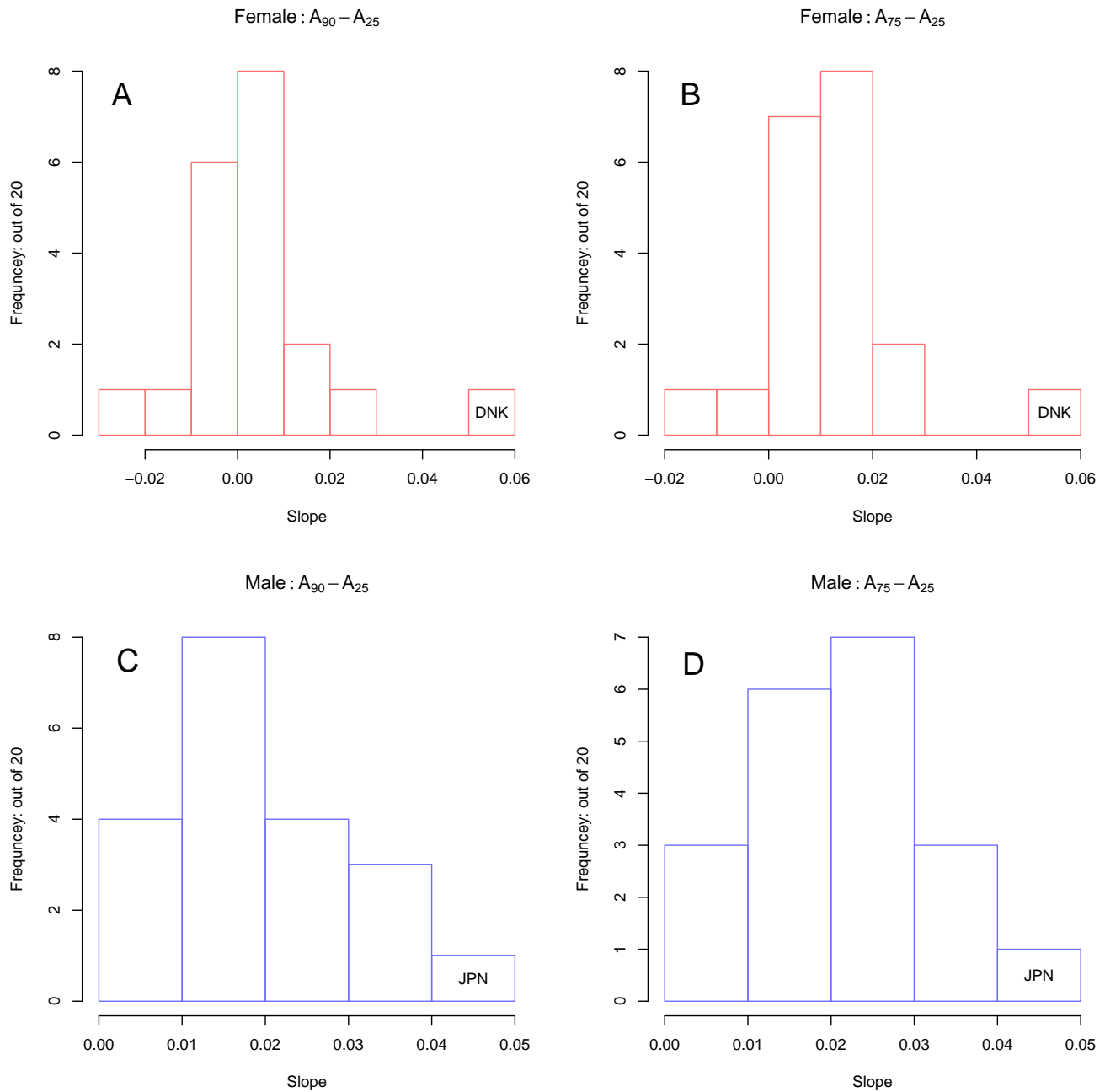


Fig. S9. Histogram of the slope of percentile gap over time. **A** the slope of $A_{90} - A_{25}$ over time for females. Only Denmark has slope larger than 0.04 which means the gap increase more than 1 year per generation (25 years). **B** the slope of $A_{75} - A_{25}$ over time for females. Only Denmark has slope larger than 0.04. **C** the slope of $A_{90} - A_{25}$ over time for males. Only Japan has slope larger than 0.04. **D** the slope of $A_{75} - A_{25}$ over time for males. Only Japan has slope larger than 0.04.

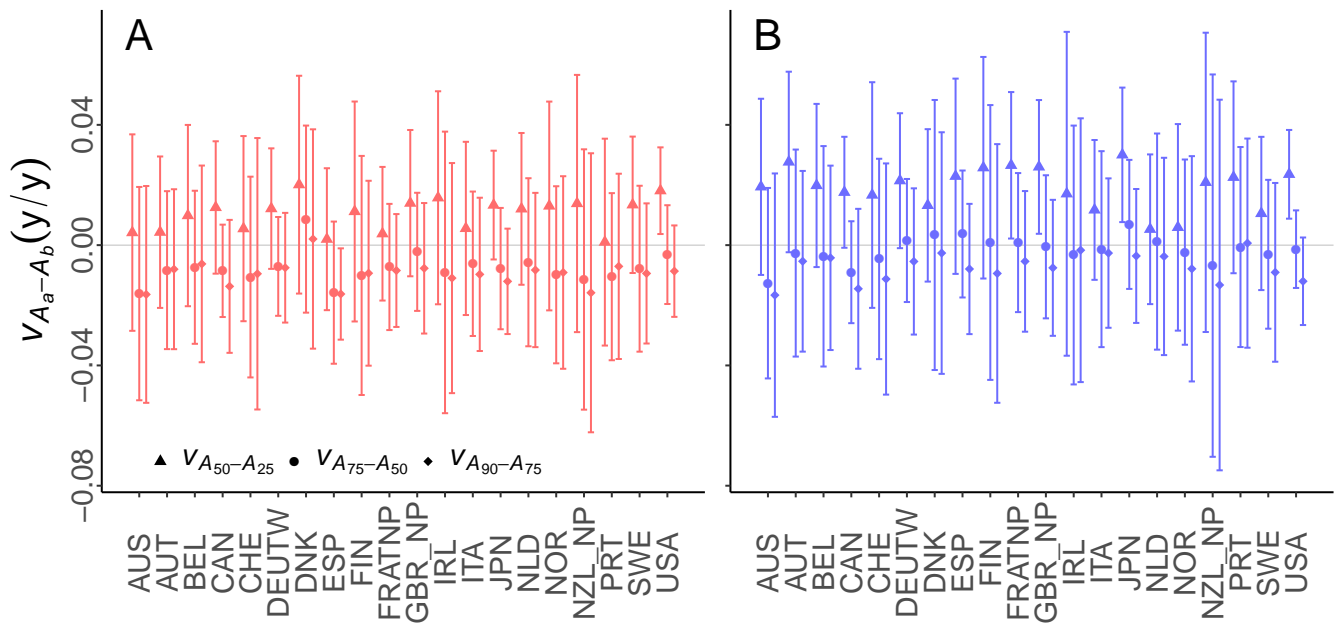


Fig. S10. A females, B males. Speeds of intervals between percentiles are indicated by, e.g., $V_{A_{50}-A_{25}}$ for the speed of the interval ($A_{50} - A_{25}$). Solid symbols show the long-term average speeds, bars show confidence intervals for annual speeds. Country codes: AUS = Australia, BEL = Belgium, CAN = Canada, CHE = Switzerland, DEUTW = West Germany, DNK = Denmark, ESP = Spain, FIN = Finland, FRATNP = France (Total Population), GBR_NP = United Kingdom, IRL = Ireland, ITA = Italy, JPN = Japan, NLD = Netherlands, NOR = Norway, NZL_NP = New Zealand, PRT = Portugal, SWE = Sweden, USA = The United States of America.

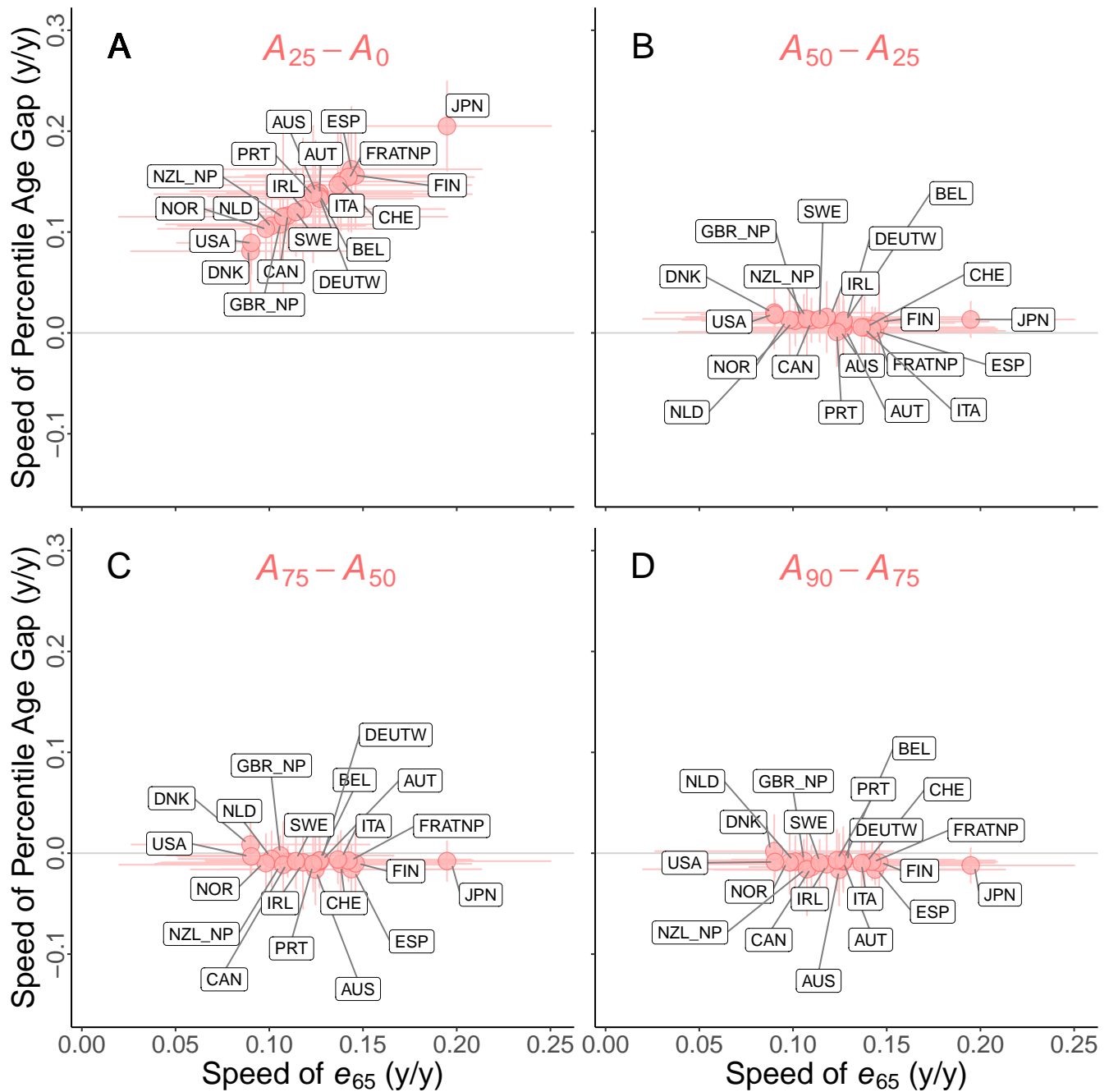


Fig. S11. Cross-country correlations for females in 20 developed countries. **A.** Vertical axis is long-term speed of A_{25} (i.e., of the distance between the 25th percentile and 65), horizontal axis is long-term speed of e_{65} (life expectancy at age 65). Each dot is a country; for each dot, the vertical and horizontal lines show 95% confidence intervals for annual speeds. There is a strong positive correlation. **B.** Vertical axis is long-term speed of the gap between A_{50} and A_{25} , horizontal axis is long-term speed of e_{65} : each dot is a country. There is nearly zero correlation. **C.** Vertical axis is long-term speed of the gap between A_{75} and A_{50} , horizontal axis is long-term speed of e_{65} : each dot is a country. There is nearly zero correlation. **D.** Vertical axis is long-term speed of the gap between A_{90} and A_{75} , horizontal axis is long-term speed of e_{65} : each dot is a country. There is nearly zero correlation. Country codes: AUS = Australia, BEL = Belgium, CAN = Canada, CHE = Switzerland, DEUTW = West Germany, DNK = Denmark, ESP = Spain, FIN = Finland, FRATNP = France (Total Population), GBR_NP = United Kingdom, IRL = Ireland, ITA = Italy, JPN = Japan, NLD = Netherlands, NOR = Norway, NZL_NP = New Zealand, PRT = Portugal, SWE = Sweden, USA = The United States of America.

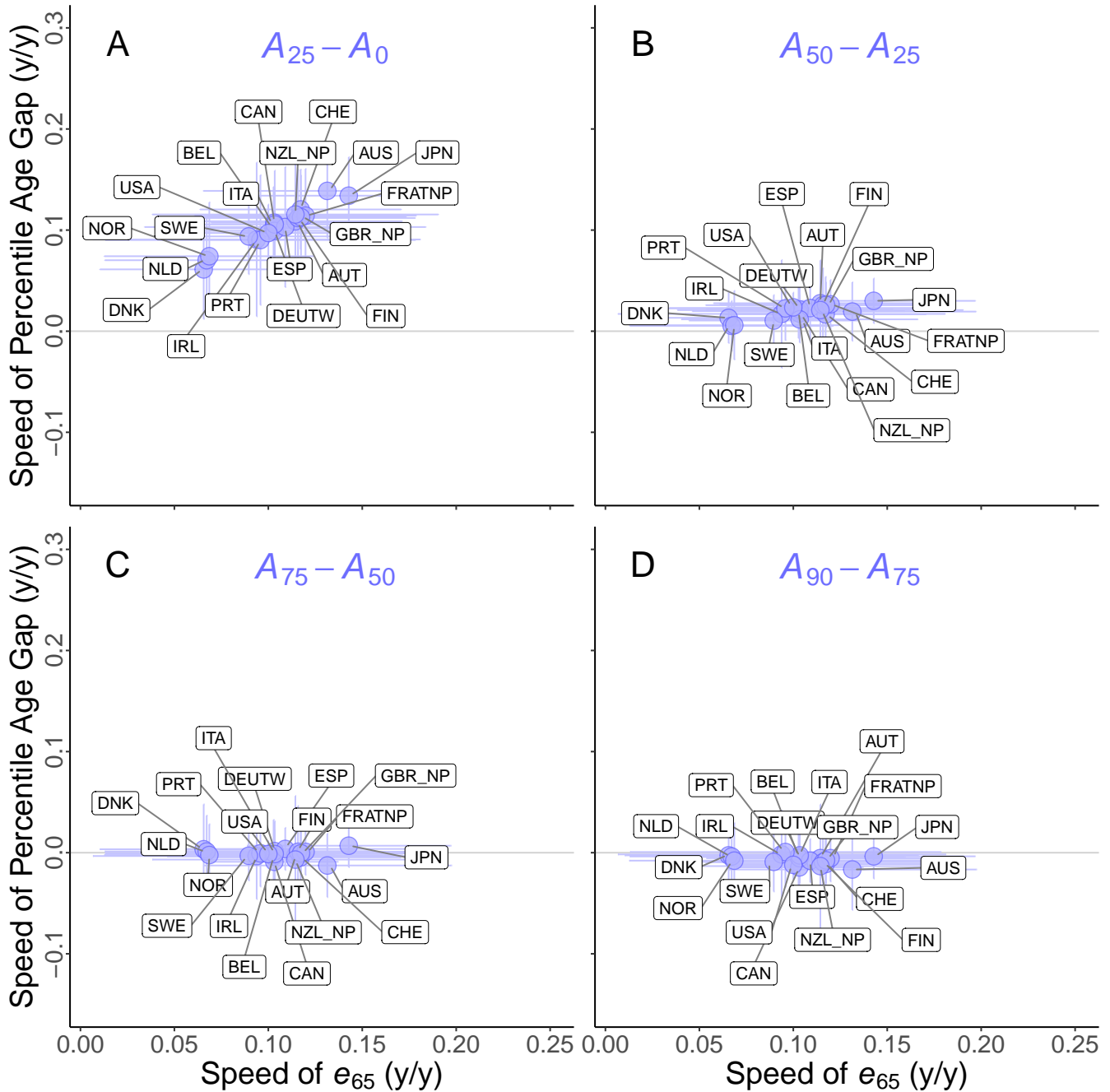


Fig. S12. Cross-country correlations for males in 20 developed countries. **A.** Vertical axis is long-term speed of percentile A_{25} (i.e., of the distance between the 25th percentile and 65), horizontal axis is long-term speed of e_{65} (life expectancy at age 65). Each dot is a country; for each dot, the vertical and horizontal lines show 95% confidence intervals for annual speeds. There is a strong positive correlation. **B.** Vertical axis is long-term speed of the gap between A_{50} and A_{25} , horizontal axis is long-term speed of e_{65} : each dot is a country. There is nearly zero correlation. **C.** Vertical axis is long-term speed of the gap between A_{75} and A_{50} , horizontal axis is long-term speed of e_{65} : each dot is a country. There is nearly zero correlation. **D.** Vertical axis is long-term speed of the gap between A_{90} and A_{75} , horizontal axis is long-term speed of e_{65} : each dot is a country. There is nearly zero correlation. Country codes: AUS = Australia, BEL = Belgium, CAN = Canada, CHE = Switzerland, DEUTW = West Germany, DNK = Denmark, ESP = Spain, FIN = Finland, FRATNP = France (Total Population), GBR_NP = United Kingdom, IRL = Ireland, ITA = Italy, JPN = Japan, NLD = Netherlands, NOR = Norway, NZL_NP = New Zealand, PRT = Portugal, SWE = Sweden, USA = The United States of America.

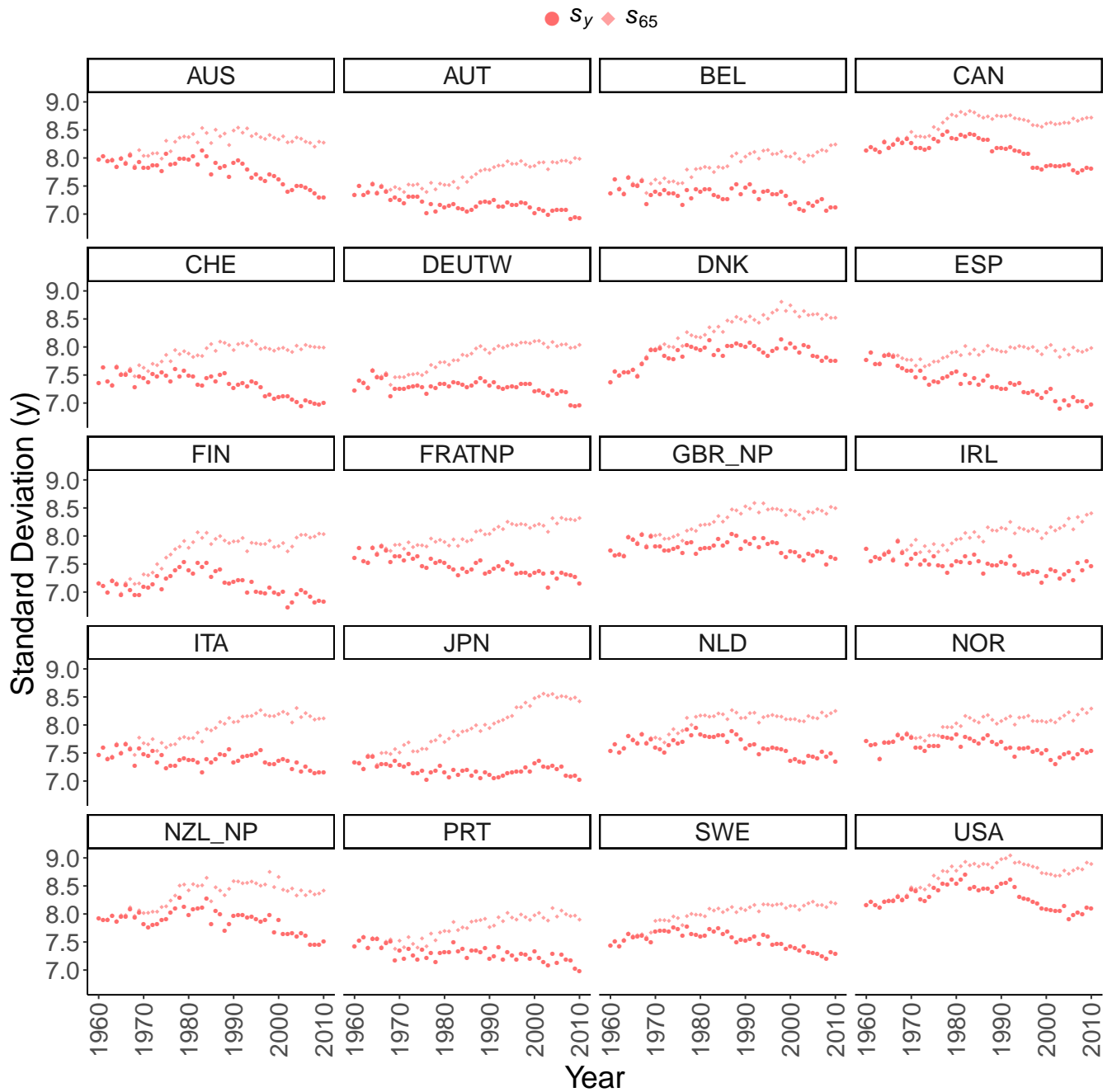


Fig. S13. Increasing variability of old-age female deaths after age $A_0 = 65$, contrasted with constant (or declining) variability of old-age deaths past an age that moves along with the survival front. Country codes: AUS = Australia, BEL = Belgium, CAN = Canada, CHE = Switzerland, DEUTW = West Germany, DNK = Denmark, ESP = Spain, FIN = Finland, FRATNP = France (Total Population), GBR_NP = United Kingdom, IRL = Ireland, ITA = Italy, JPN = Japan, NLD = Netherlands, NOR = Norway, NZL_NP = New Zealand, PRT = Portugal, SWE = Sweden, USA = The United States of America.

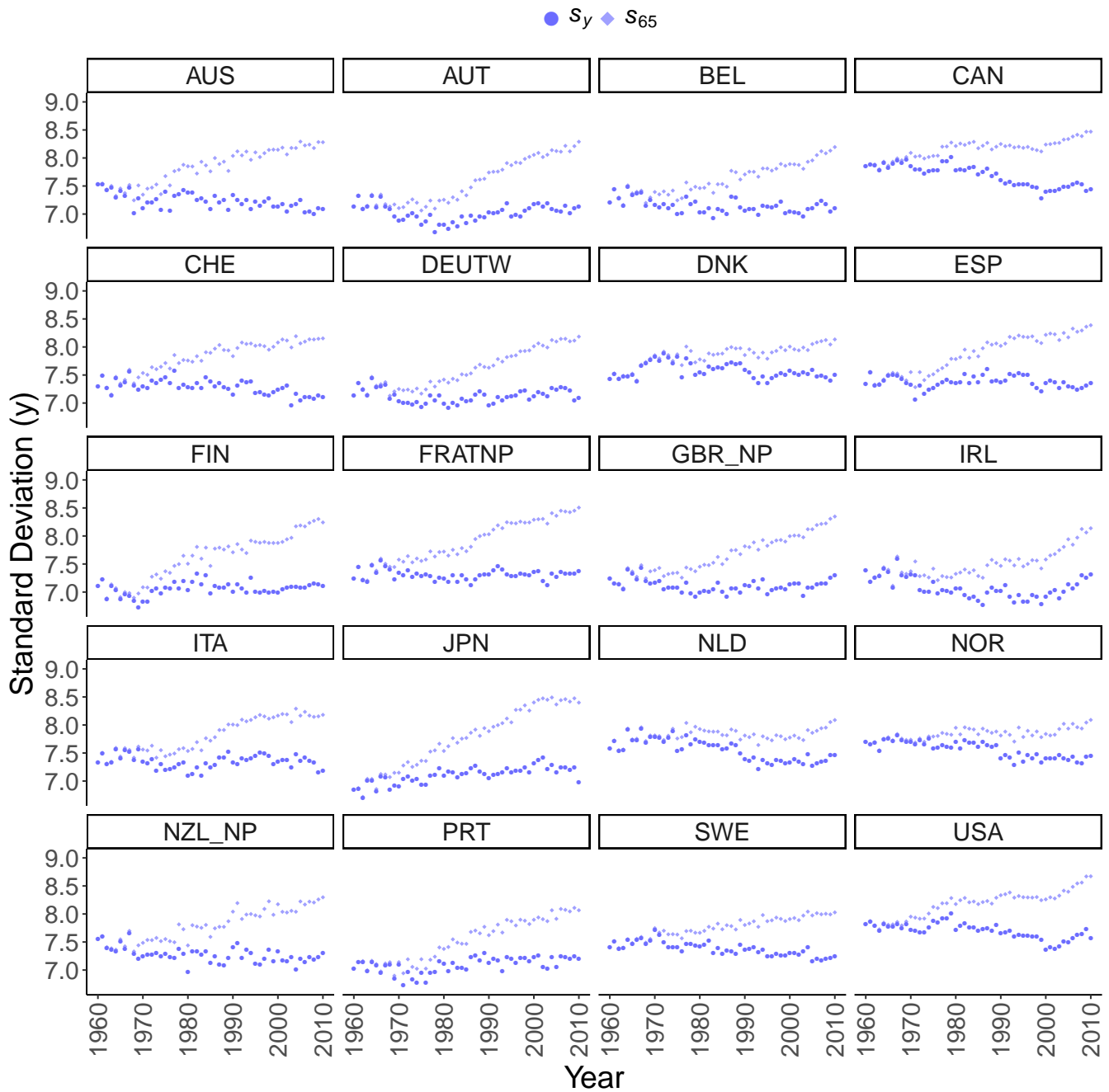


Fig. S14. Increasing variability of old-age male deaths after age $A_0 = 65$, contrasted with constant (or declining) variability of old-age deaths past an age that moves along with the survival front. Country codes: AUS = Australia, BEL = Belgium, CAN = Canada, CHE = Switzerland, DEUTW = West Germany, DNK = Denmark, ESP = Spain, FIN = Finland, FRATNP = France (Total Population), GBR_NP = United Kingdom, IRL = Ireland, ITA = Italy, JPN = Japan, NLD = Netherlands, NOR = Norway, NZL_NP = New Zealand, PRT = Portugal, SWE = Sweden, USA = The United States of America.