Mortality Shocks in Insured Populations during COVID-19 and Implications for Annuity Life Tables

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Outline

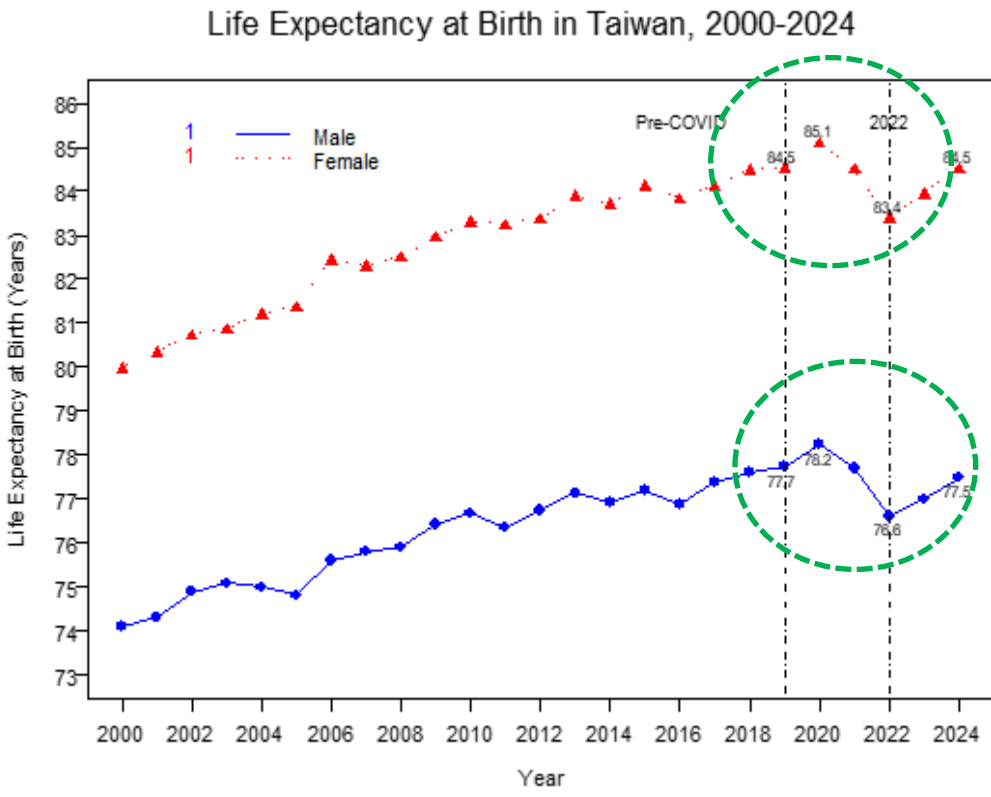
- Motivation: Longevity risk, population aging, and changes in mortality during COVID-19.
- Data and methodology: Data, no-COVID mortality, COVID-19 death estimates, and validation.
- Empirical Analysis: National, Life Insurance, Annuity, and comparison of the three populations.
- Actuarial implications: Effects on life expectancy and annuity life tables, limitations, and future research.

Motivation

Longer Life Makes Longevity Risk More Important for Annuities

- People are living longer and spending more years in retirement. This makes mortality assumptions more important for annuity pricing and reserves.
- COVID-19 gives us a chance to ask an important question: Was the mortality change temporary, or did the long-term trend change?

- **Life expectancy increased before COVID-19**
  - e_0 increased from **74.1 to 77.7 years for males** and from **80.0 to 84.5 years for females** during 2000–2019.
- **COVID-19 clearly interrupted this improvement**
  - From 2020 to 2022, e_0 fell by **1.63 years for males** and **1.70 years for females**.
- **Recovery after 2022**
  - By 2024, females had almost returned to the 2019 level, but males were still 0.26 years lower.



Before answering this question, let us first look at why this issue is especially important for Taiwan

Population Aging and the Growing Need for Retirement Protection

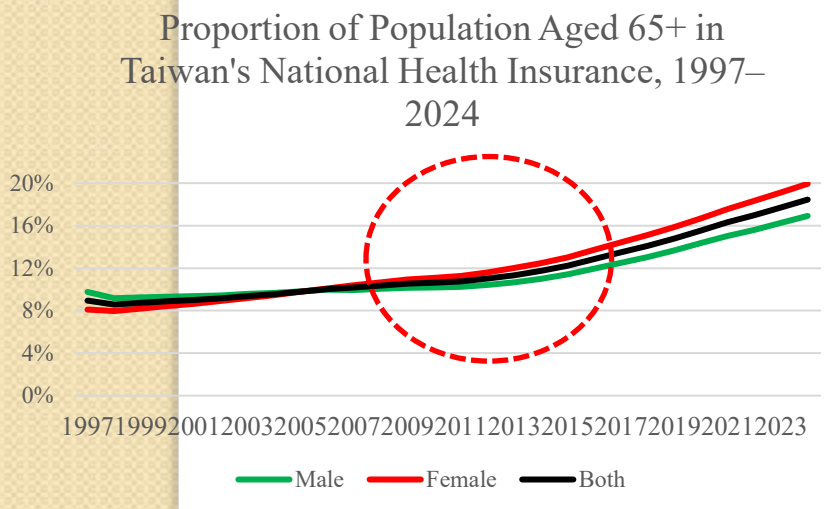
- Taiwan is aging quickly, while fertility is low and the working-age population is shrinking
  - Rapid population aging makes longevity and mortality risk more important.

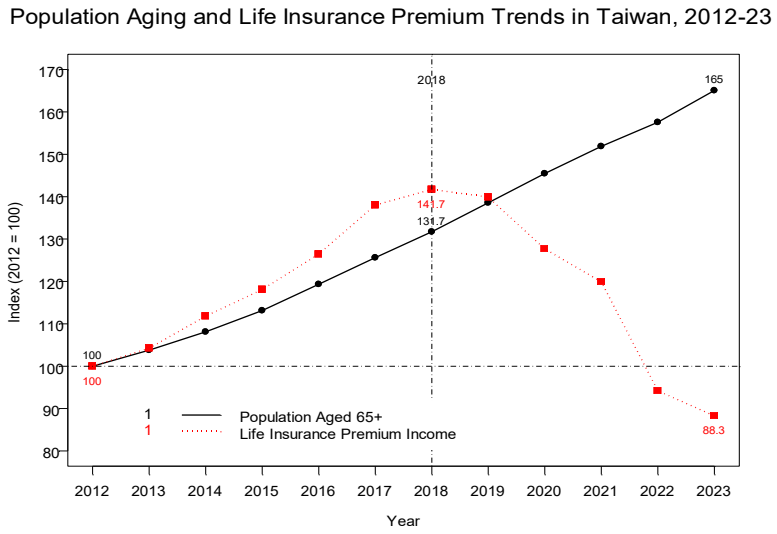
EX: In the left figure, the share of people aged 65+ rises clearly over time, **especially after around 2015**. The population aged 65+ increased from 1.83 million in 1997 to 4.42 million in 2024, while the population aged 0–14 fell from 4.53 million to 2.68 million.

- Population aging continued, but life-insurance premiums did not grow at the same pace.

EX: In the right figure, the black line shows the population aged 65+, and the red dotted line shows life-insurance premium income. Both are shown as an index with 2012 equal to 100. The black line keeps rising, but the red line turns downward after its peak. From 2012 to 2023, the population aged 65+ increased by 65.0%, while life-insurance premium income decreased by 11.7%.

  - **After 2018**, the gap became much clearer. Growing retirement needs did not lead to similar growth in the life-insurance market.

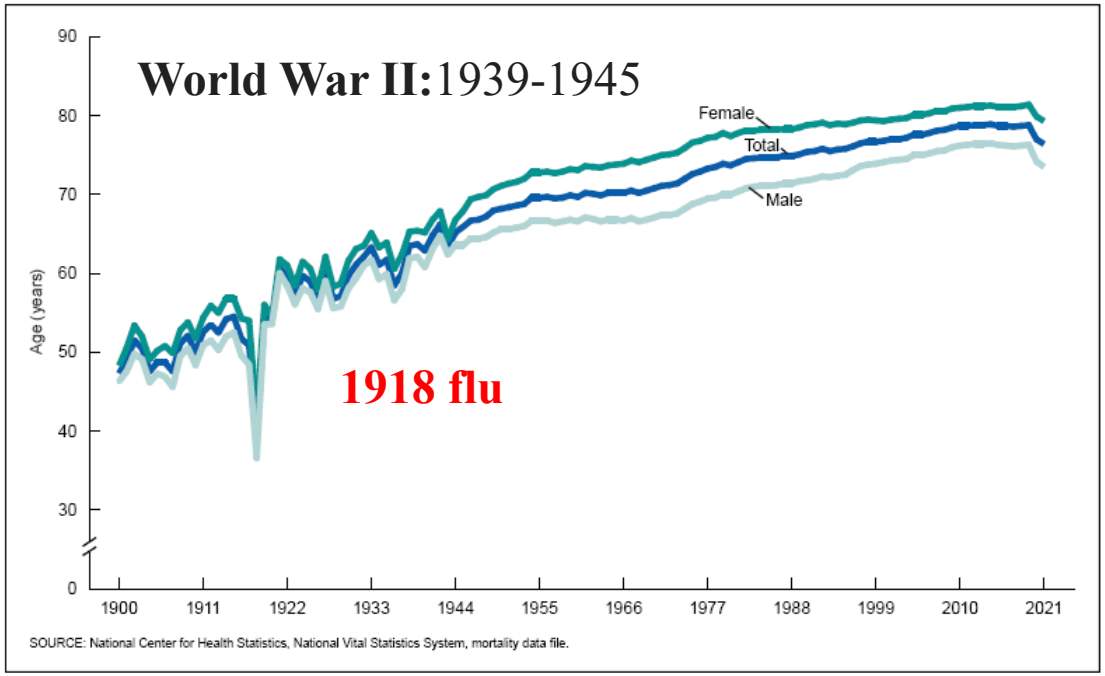




The aging population is growing faster than the life-insurance marke. So, should the COVID-19 shock be included in future annuity life tables?

Is COVID-19 a Temporary Mortality Shock for Annuity Life Tables?

- Major mortality events can interrupt long-term improvements in life expectancy. EX: The 1918 flu caused a large but temporary drop in life expectancy.
- The figure shows the long-term trend in U.S. life expectancy. The three lines show female, total, and male life expectancy. 1918 flu: Life expectancy fell by about 12 years. But the decline was temporary, and life expectancy later returned to its long-term upward trend.
- The same question applies to COVID-19: temporary shock or long-term change? We need to separate the two before using COVID-period mortality in future annuity life tables.



Our analysis follows four steps: No-COVID Baseline → Estimated Direct COVID → Residual → Life-Table Implications

A large mortality shock does not always mean a long-term change. So, how can we separate the COVID shock from the long-term mortality trend?

Data and methodology

Data Sources and Population Differences

- The three populations use different data periods and different exposure measures. COVID-19 data are also not equally available.
- National COVID-19 deaths are directly observed. For Life Insurance and Annuity, COVID-19 deaths must be estimated.

➔So, we compare each population with its own no-COVID baseline, not with raw mortality levels.

- The table:

National: mortality data 2000–2024; COVID-19 deaths are observed. Life Insurance: mortality data 1991–2022; COVID-19 deaths are estimated; health selection may be present. Annuity: mortality data 2016–2023; the pre-COVID period is short; COVID-19 deaths are estimated.

Population	Mortality Data	COVID-19 Deaths	Main Feature
National	2000–2024	Observed, 2020–2024	Population benchmark
Life Insurance	1991–2022	Estimated, 2020–2022	Long history; health selection
Annuity	2016–2023	Estimated, 2020–2023	Short pre-COVID history; health selection

Different data structures require different no-COVID baselines. Next, we define how we measure the mortality shock.

Main Mortality-Shock Indicators

- **Mortality Ratio**

$$R_{x,t} = \frac{m_{x,t}^{obs}}{m_{x,t}^{0}}$$

- $m_{x,t}^{obs}$: observed mortality rate at age x in year t
- $m_{x,t}^{0}$: no-COVID mortality rate at age x in year t .

Note: $R_{x,t} = 1$: Observed mortality equals the no-COVID baseline.$R_{x,t} > 1$: Observed mortality is higher than the no-COVID baseline.$R_{x,t} < 1$: Observed mortality is lower than the no-COVID baseline.

- **Relative Mortality Shock**

$$\text{Relative Mortality Shock}_{x,t} = 100\left(\frac{m_{x,t}^{obs}}{m_{x,t}^{0}} - 1\right)$$

- That is Relative Mortality Shock=(Mortality Ratio−1)×100% , it shows how much mortality is above or below the no-COVID baseline, as a percentage.

These measures show the mortality shock. Next, we measure its impact in terms of deaths and separate its components.

we change mortality rates into death counts.

- Expected Deaths under the No-COVID Baseline: Expected deaths under no COVID are calculated as exposure multiplied by the no-COVID mortality rate. $D^{0}_{x,t} = E_{x,t} m^{0}_{x,t}$

, where $E_{x,t}$: population or exposure at age x in year t. $m^{0}_{x,t}$: no-COVID mortality rate at age x in year t

- Total Excess Deaths: Excess deaths are observed deaths minus expected deaths under the no-COVID baseline. $D^{Excess}_{x,t} = D^{obs}_{x,t} - D^{0}_{x,t}$, where $D^{obs}_{x,t}$: observed number of deaths at age x in year t
- COVID-19 Share of Observed Deaths: COVID share shows the percentage of observed deaths attributed to direct COVID-19. $COVIDShare_{x,t} = \frac{100(\hat{D}^{COVID}_{x,t})}{D^{obs}_{x,t}}$, where $\hat{D}^{COVID}_{x,t}$: direct COVID-19 deaths. For National, they are officially observed; for LI and Annuity, they are model-estimated.
- Additive Decomposition of Excess Deaths: Excess deaths are divided into two parts: direct COVID and residual. $D^{obs}_{x,t} - D^{0}_{x,t} = \hat{D}^{COVID}_{x,t} + D^{Residual}_{x,t}$
  - Residual is the part not explained by estimated direct COVID deaths. It should not automatically be called indirect COVID mortality.

Note: Residuals may include non-COVID mortality changes, mortality improvement, indirect pandemic effects, model forecast error, baseline misspecification, and estimation error.

These measures depend on the no-COVID baseline. So, how do we estimate this baseline?

- LC model:

$$\log m_{x,t} = a_x + b_x k_t + \varepsilon_{x,t}$$

with $\sum_x b_x = 1$ and $\sum_t k_t = 0$, a_x average mortality level at age x, b_x sensitivity to mortality change at age *x*, and k_t describes the overall mortality trend over time.

- We use the LC model to estimate the mortality trend and construct the no-COVID baseline.

- No-COVID Mortality Rate:

$$m_{x,t}^0 = \exp\left(\hat{a}_x + \hat{b}_x \hat{k}_t\right)$$

$m_{x,t}^0$: estimated no-COVID mortality rate

LC provides the expected mortality path without COVID-19. But how can we check whether this baseline is reliable?

How Do We Validate the LC No-COVID Baseline?

Backtesting shows how large LC forecast errors were in normal pre-COVID years. We use these historical errors to evaluate the COVID-period forecast errors.

- We use three backtesting designs: Set A, Set B, and Set C. The three sets test how LC forecasts depend on the training period and forecast horizon.
  - Set A: Recent training periods with short- to medium-term forecasts (H1–H10). Note: H = forecast horizon; H1 means one year ahead.
  - Set B: 15-year rolling windows. It provides our main National no-COVID baseline.
  - Set C: Earlier starting years to test the effect of earlier mortality-improvement history.

Set	Historical design	Purpose
Set A	Training starts in 2005; expands from 2005–2014 to 2005–2018	Recent short- to medium-term backtesting
Set B	15-year rolling windows; main baseline: 2005–2019	Main National no-COVID baseline and normal-error reference
Set C	Earlier-start windows: 1995–2009 to 1995–2016	Test sensitivity to earlier mortality history

Before showing the backtesting results, we first define the forecast horizon and prediction error.

Forecast Horizon and Prediction Error (used in backtesting)

- H: forecast horizon: the number of years from the end of training to the forecast year.

$$H = \text{forecast year} - \text{training-end year}$$

H shows how far the forecast year is from the training period. EX: For the 2005–2019 training period: 2020 = H1, 2021 = H2, 2022 = H3, 2023 = H4, 2024 = H5.

- Relative Prediction Error (PE)

$$PE_{x,t} = 100\frac{m_{x,t}^{obs} - m_{x,t}^{0}}{m_{x,t}^{0}}$$

- $m_{x,t}^{obs}$:observed mortality rate
- $m_{x,t}^{0}$: predicted no-COVID mortality rate
- PE = 0: Observed = predicted; PE > 0: Observed > predicted; PE < 0: Observed < predicted

Note: Prediction Error (PE) and Relative Mortality Shock formulas are the same. In historical backtesting, we call it prediction error. During COVID, we use the same measure to describe the mortality shock.

H tells us how far we forecast, and PE measures the forecast error. Next, we summarize these errors and check whether they are unusual.

Forecast Error and Mortality Abnormality

- Mean Prediction Error: Average relative prediction error .
- Root Mean Squared Error (RMSE): Overall size of prediction errors; smaller is better.
- Log Prediction Error (LPE):LPE measures the mortality gap on the log scale.

$$LPE_{x,t} = \log\left(\frac{m_{x,t}^{obs}}{m_{x,t}^{0}}\right)$$

- Standardized Mortality Abnormality Z

$$Z_{x,t} = \frac{PE_{x,t}^{Pandemic} - MeanPE_{x,H}}{SD(PE_{x,H})}$$

- Z shows how unusual the COVID-period prediction error is compared with historical errors. Z does not measure mortality itself.
- We use ±1.96 to identify unusual errors, not for a formal test.
- H1–H3: primary evidence; H4: exploratory; H5: insufficient history for stable Z classification.

Historical errors help us identify unusual COVID-period deviations. Next, we build a no-COVID baseline for each population.

No-COVID Baselines by Population

- The three populations have different mortality histories and risk structures. So, we build a separate no-COVID baseline for each population.
- The table shows the data, the no-COVID baseline, and why we use it for each population.
- National has a long mortality history, so we use a National LC model. LI also has a long history, so we build its own LC model. Annuity has only four pre-COVID years of data (2016–2019), so we borrow the LI trend and adjust it to the Annuity level.

Population	Data Basis	No-COVID Baseline	Why This Method?
National	Long national mortality history	$m_{x,t}^{Nat,0}$:National LC forecast	Long historical data are available
Life Insurance	Long LI mortality history	$m_{x,t}^{LI,0}$: Sex-specific LI LC forecast	Keeps the LI mortality trend and selection pattern
Annuity	2016–2023 only; four pre-COVID years	$m_{x,t}^{AN,0} = c(x)m_{x,t}^{LI,0}$= Annuity adjustment factor ×LI long-term trend	Keeps the Annuity mortality level

Each population has its own no-COVID baseline. Next, I explain the Annuity adjustment factor.

Annuity Adjustment Factor

- Annuity has only four pre-COVID years. This is too short to estimate a long-term trend. So, we use the LI trend and adjust it to the Annuity mortality level.
- Pre-COVID Mortality:
  - $m_x^{AN,pre}$:Annuity mortality rate at age x, based on total deaths and total exposure during 2016–2019.

$$m_x^{AN,pre} = \frac{\sum_{t=2016}^{2019} D_{x,t}^{AN}}{\sum_{t=2016}^{2019} E_{x,t}^{AN}}$$

  - $m_x^{LI,pre}$: LI mortality rate at age x, based on 2016–2019 data.

$$m_x^{LI,pre} = \frac{\sum_{t=2016}^{2019} D_{x,t}^{LI}}{\sum_{t=2016}^{2019} E_{x,t}^{LI}}$$

- Annuity Adjustment factor: c(x) adjusts the LI mortality level to the Annuity mortality level at each age.

$$c(x) = \frac{m_x^{AN,pre}}{m_x^{LI,pre}}$$

  - **c(x)=1:** Annuity and LI have the same mortality level.; **c(x)<1:** Annuity mortality is lower than LI.; **c(x)>1:** Annuity mortality is higher than LI.
- Annuity No-COVID mortality rate:

$$m_{x,t}^{AN,0} = c(x) m_{x,t}^{LI,0}$$

  - $m_{x,t}^{LI,0}$: LI No-COVID mortality rate.

LI gives the long-term trend, and c(x) adjusts it to the Annuity level. Next, we explain why direct COVID deaths must be estimated.

Why Do We Need to Estimate Direct COVID Deaths?

- National COVID deaths are directly observed from cause-of-death data.
- For LI and Annuity, direct COVID deaths are not separately observed in our data. So, we estimate direct COVID deaths using National COVID mortality and the exposure of each insured population.
- Health-Selection Factor
  - s(x) is used to adjust for the mortality difference between insured and National populations.

$$s(x) = \frac{m_x^{LI,pre}}{m_x^{Nat,pre}}$$

- s(x) compares LI mortality with National mortality before COVID-19. The main period is 2015–2019.
- s(x)<1: LI mortality is lower than National mortality.; s(x)=1: LI and National mortality are the same.

EX: $m_x^{LI,pre}$=0.008, $m_x^{Nat,pre}$=0.01, then s(x)=0.008/0.01=0.8. It means LI mortality is 80% of National mortality at this age.

c(x): adjusts the Annuity no-COVID level. s(x): adjusts estimated direct COVID deaths. Next, we use s(x) to build three COVID scenarios.

Three Scenarios for Direct COVID Deaths

- We use three scenarios to allow for different levels of health selection. The three scenarios show a range of possible direct COVID estimates.
- S0 has no adjustment, S0.5 has a partial adjustment, and S1 has a full adjustment.

➢ S0: No Adjustment: $\widehat{D}_{x,t}^{LI,COVID,S0} = E_{x,t}^{LI} m_{x,t}^{Nat,COVID}$

S0 directly uses the National COVID mortality rate.

➢ S0.5: Partial Adjustment: $\widehat{D}_{x,t}^{LI,COVID,S0.5} = E_{x,t}^{LI} m_{x,t}^{Nat,COVID} \sqrt{s(x)}$

S0.5 uses part of the health-selection effect. It does not mean 50% of COVID deaths. It is simply an intermediate adjustment between S0 and S1. $\sqrt{s(x)}$ gives an adjustment between S0 and S1 when $0<s(x)<1$.

➢ S1: Full Adjustment: $\widehat{D}_{x,t}^{LI,COVID,S1} = E_{x,t}^{LI} m_{x,t}^{Nat,COVID} s(x)$

S1 uses the full health-selection effect.

- Simple Example

If s(x)=0.8, LI exposure = 10,000, and National COVID mortality = 0.01:

Scenario	Adjustment	Estimated deaths
S0	1	100
S0.5	$\sqrt{0.8}$=0.894	89.4
S1	0.8	80

- **The same three-scenario idea is also used for Annuity**.

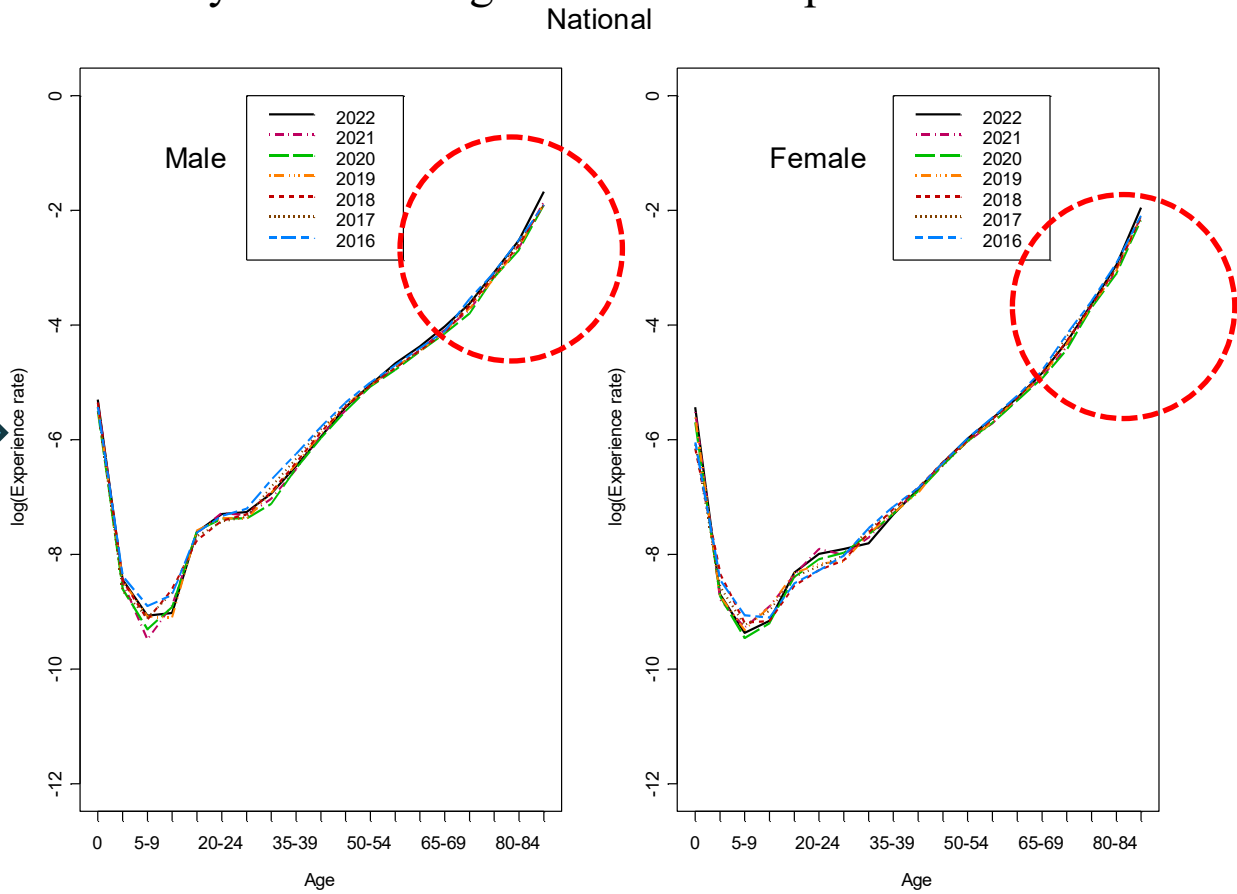
With the methods defined, we now begin with the National population.

Empirical Analysis: National Population

National Observed Mortality by Age, 2016–2022

- This figure shows observed mortality before and during COVID-19.
- The left panel shows males, and the right panel shows females. Each line represents one year from 2016 to 2022.
- In 2022, mortality at older ages is higher than in most previous years for both males and females. This suggests a possible mortality shock during the COVID-19 period.

- The age pattern is similar across years, and the yearly lines are close at many ages, but differences appear at some ages during the COVID period.
- However, the observed curves alone cannot tell us whether these differences are unusually large.



So, we next compare these changes with normal historical forecast errors.

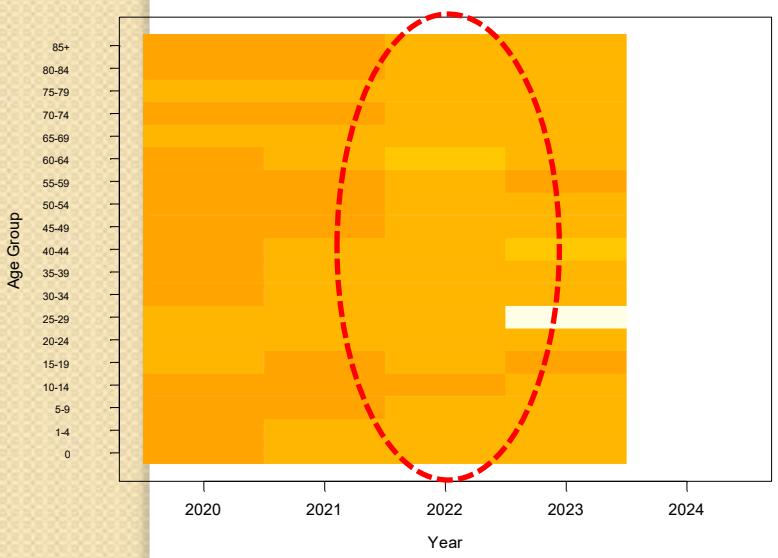
National Mortality Abnormality during COVID-19

- This heatmap shows whether mortality during COVID-19 was unusually high compared with historical LC forecast errors.
- Darker orange means a lower Z, while brighter yellow means a higher Z.
- The clearest widespread mortality shock appears in 2022, especially for males.
  Male: 16 of 19 age groups had Z>1.96. Female: 9 of 19 age groups had Z>1.96.

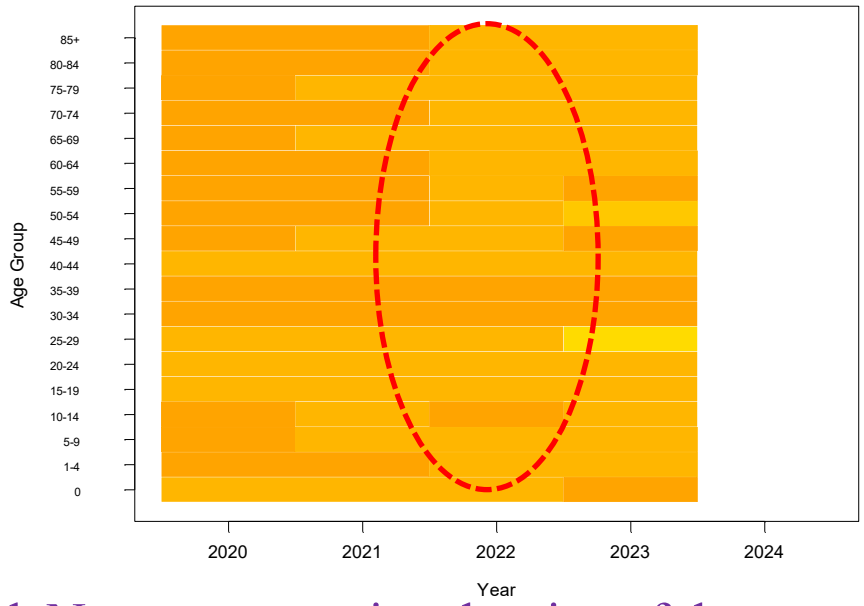
Note: The white 2024 column means that Z is unavailable. It does not mean zero or an extremely high value.

- This means the 2022 mortality increase was unusually large compared with normal historical forecast errors.

Male: Standardized Mortality Deviation relative to Normal LC Error



Female: Standardized Mortality Deviation relative to Normal LC Error

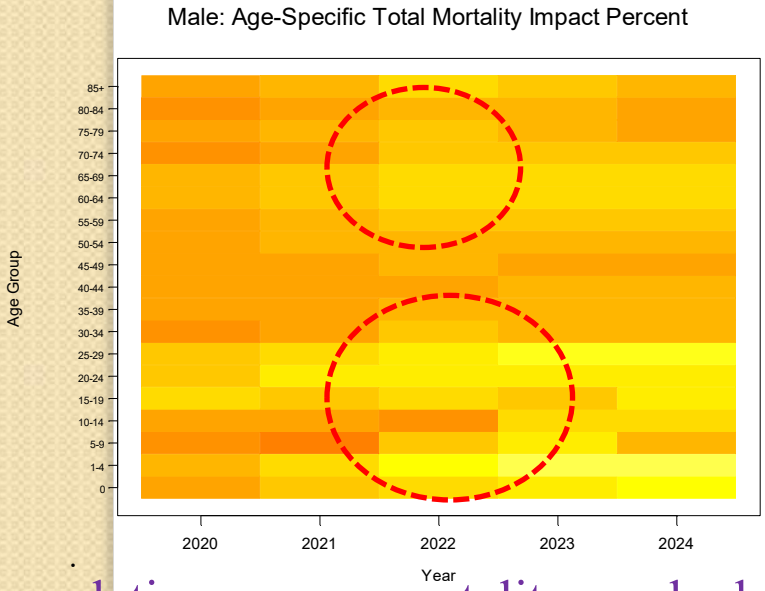


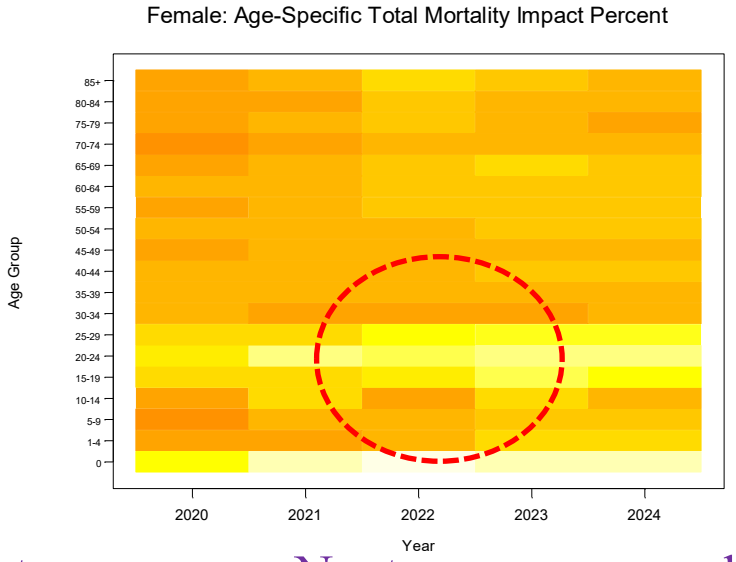
The 2022 shock was unusually widespread. Next, we examine the size of the mortality impact across age groups.

Relative Excess Mortality by Age and Year

- This heatmap shows the relative excess mortality(REM) by age and year. A positive value means observed mortality is higher than the no-COVID baseline. A negative value means it is lower.

  Note: Negative values are possible when observed mortality is below the no-COVID baseline
- Brighter colors mean a larger positive mortality shock, while darker colors mean a smaller or negative shock.
- REM differs greatly across age groups. Large shocks are not limited to older ages.
  - For example, for males aged 25–29, the impact increased from 10.27% in 2020 to 36.62% in 2022 and 54.38% in 2024.
- Some younger ages show large percentages, but this does not mean that direct COVID deaths were also large at those ages.



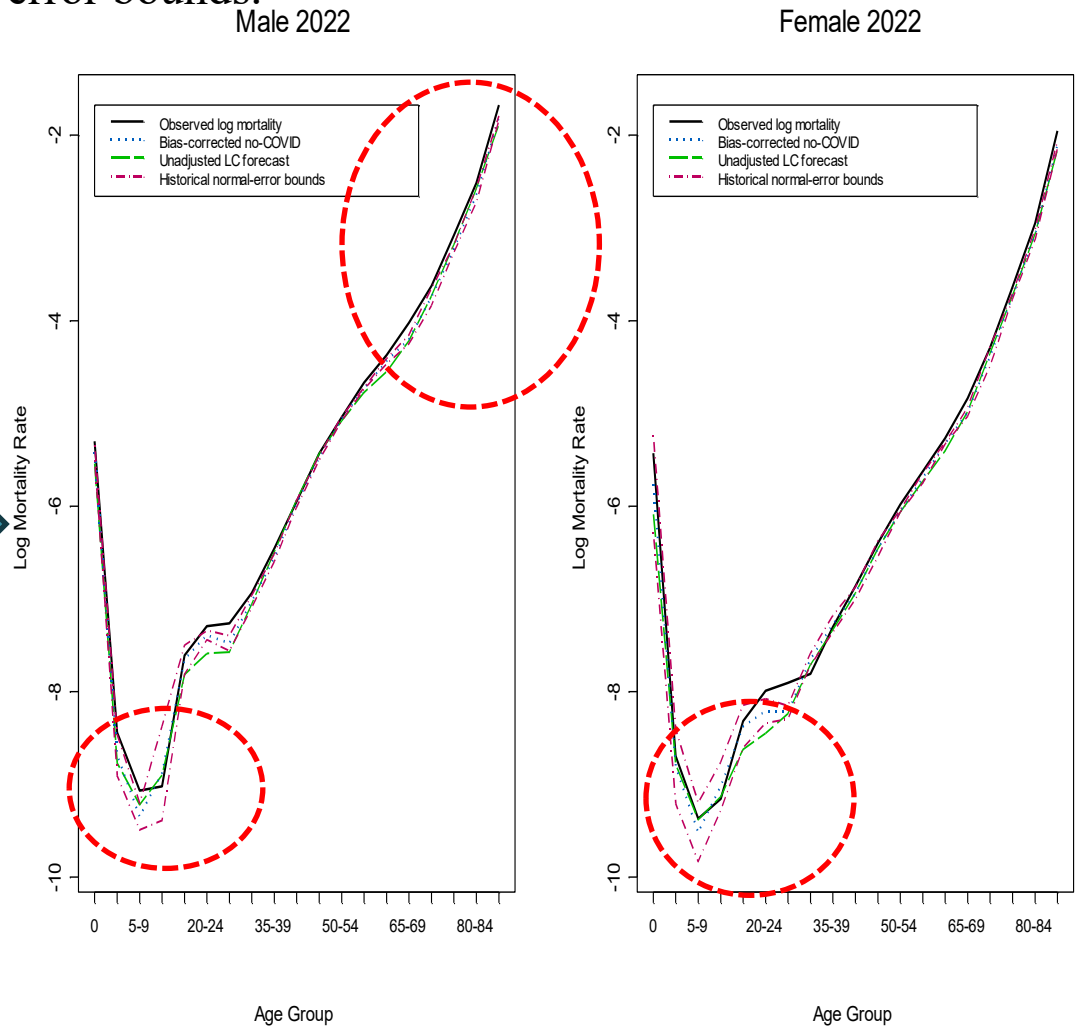


The relative excess mortality can be large at many ages. Next, we compare observed mortality with the no-COVID baseline in 2022.

Observed vs. No-COVID Baseline in 2022

- This figure compares observed mortality with the no-COVID baseline in 2022.
- Black: observed log mortality. Blue: bias-corrected no-COVID baseline. Green: original LC forecast. Pink: historical normal-error bounds.

- Observed mortality is higher than the no-COVID lines at many ages.
- The 2022 mortality shock is spread across many age groups.
- At younger ages, the two LC forecasts differ more.

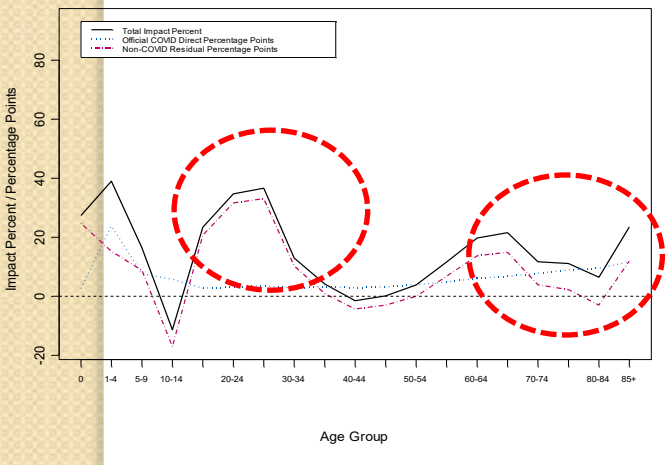


The 2022 shock was broad across age groups. Next, we separate it into direct COVID and residual parts.

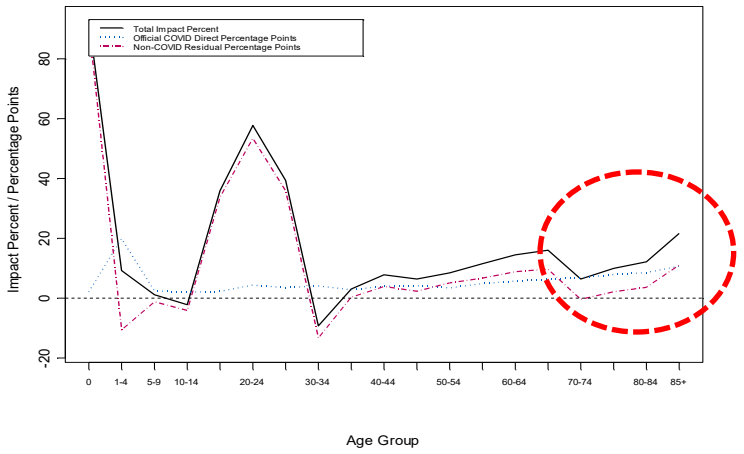
Direct COVID and Residual Mortality Shock in 2022

- This figure shows how the total mortality shock is divided into direct COVID and residual parts . $Shock_{x,t}^{Total} = Shock_{x,t}^{COVID} + Shock_{x,t}^{Residual}$
- Black: total relative mortality shock. Blue: direct COVID shock. Red: residual shock.
- At some younger ages, the total shock is large, but the direct COVID shock is small. Most of the difference is residual.
  - EX: Male age 20–24: total = 34.70%, direct COVID = 3.11%, residual = 31.59%.
- At some older ages, direct COVID explains a larger part of the total shock.
  - EX: Male age 75–79: total = 11.11%, direct COVID = 8.89%, residual = 2.22%. Female age 80–84: total = 12.13%, direct COVID = 8.52 points, residual=3.6%
- Residual does not mean indirect COVID deaths only. It may also include other mortality changes and model error.

Male: Total, Official COVID, and Residual Impact, 2022



Female: Total, Official COVID, and Residual Impact, 2022



Next, we summarize the main National findings.

National Population: Main Findings

- 1. The shock was small in 2020, but became widespread in 2022.
- 2. In 2022, mortality was above the no-COVID baseline in 17 of 19 age groups for both males and females.
- 3. A larger Z-score means a more unusual mortality shock: Z was above 1.96 in 16 male groups and 9 female groups. The shock was broad for both sexes, but more unusual for males.
- 4.Large mortality shocks were not limited to older ages. Some younger age groups also showed large increases.
- 5. At younger ages, the residual was often more important. **At older ages, direct COVID became more important.**

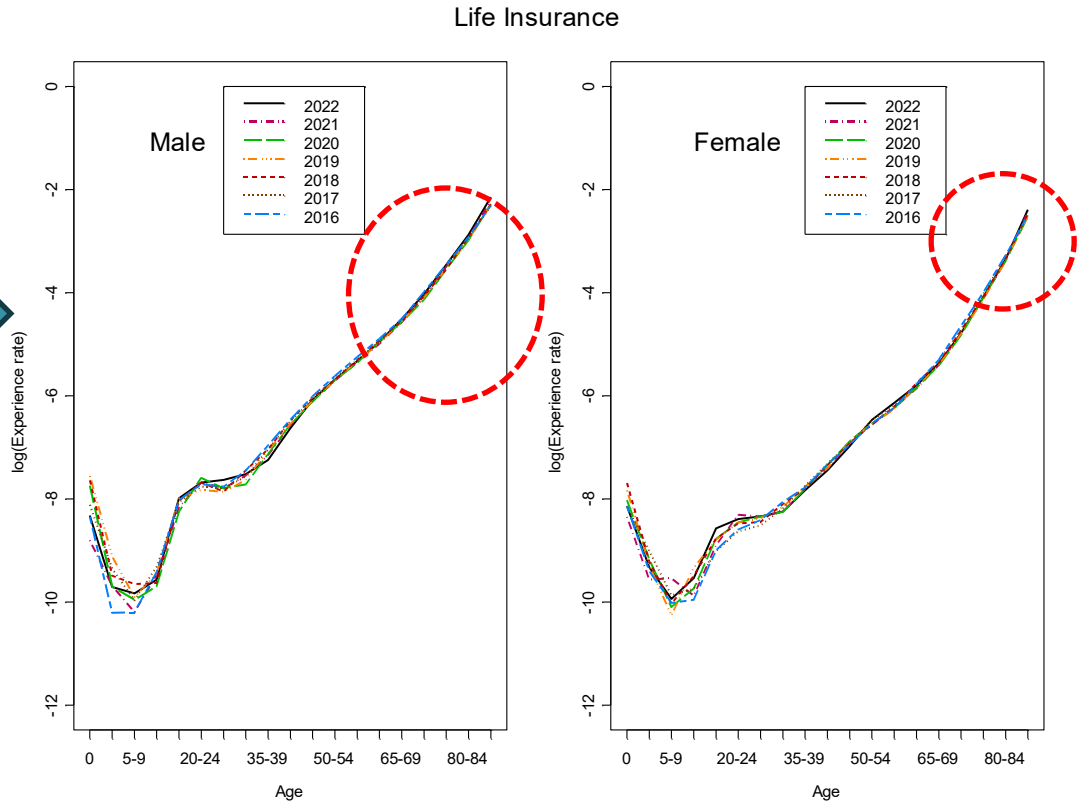
Do we see the same pattern in insured lives? Next, we examine the Life-Insurance population.

Life-Insurance Population Empirical Analysis

Life-Insurance Observed Mortality by Age, 2016–2022

- This figure shows the observed mortality experience of the Life-Insurance population.
- The left panel shows males, and the right panel shows females.
- For males, 2022 mortality is generally higher at ages 65+. For females, this pattern is more evident at ages 80+. This may reflect a COVID-related mortality shock at older ages.

- The general age pattern is stable across years, but mortality levels differ from the National population.
- This difference may reflect the different risk structure of insured lives.
- Therefore, National mortality should not be used directly as the LI baseline.



Therefore, we analyze LI separately using its own mortality history and exposure data.

Life-Insurance Data and Analysis

- LI has a different mortality level and risk structure from National.
  - Therefore, we analyze LI separately.

- LI mortality data cover 1991–2022.
  - This long history allows us to build an LI-specific LC model.

- Mortality is analyzed separately by sex and age.
  - We use LI exposure, not the National population.

- Direct COVID deaths are not observed in the LI data.
  - Therefore, they must be estimated.

Because direct COVID deaths are estimated, we need to check whether the estimates are reasonable.

How Do We Check the LI COVID Estimates?

- **We use three checks to see whether the estimated COVID deaths are reasonable.**

➢ 1. Move toward the no-COVID baseline.

After COVID removal, mortality should move closer to the no-COVID baseline

Note: If $\left|LPE_{x,t}^{LI,Rem}\right| < \left|LPE_{x,t}^{LI,Obs}\right|$

, the COVID estimate moves mortality in the expected direction.

➢ 2.Return to the historical error range.

The remaining error should move back toward the historical LC error range.

3.Check S0, S0.5, and S1.

The main result should be similar under S0, S0.5, and S1.

This checks whether the results depend strongly on the health-selection assumption.

Note:

These checks support the reasonableness of the estimates, but they do not prove that the estimates are exact.

Now, let us look at the estimated COVID deaths in LI.

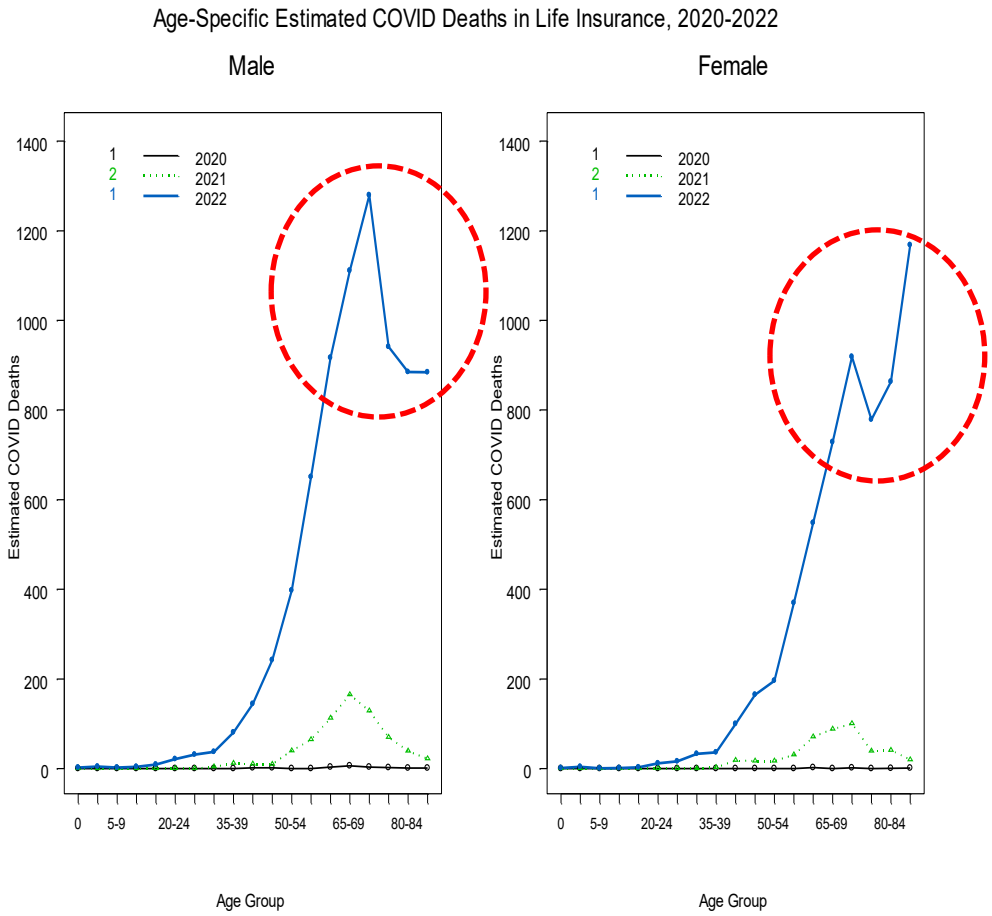
LI: Estimated COVID Deaths by Age

- This figure shows estimated direct COVID deaths by age in LI. The left panel shows males and the right panel shows females. Black represents 2020, green represents 2021, and blue represents 2022.

- Estimated COVID deaths were much higher in 2022 than in 2020 and 2021.
- In 2022, under S0.5, estimated COVID deaths were 7,643 for males and 5,941 for females.
  - They accounted for 7.62% and 7.70% of observed deaths, respectively.

Males had more estimated COVID deaths, but the share of observed deaths was similar for males and females.

- COVID deaths were concentrated at older ages, especially among females.
  - For females in 2022, age 65+ accounted for 75.03% and age 75+ for 47.30% of estimated COVID deaths.

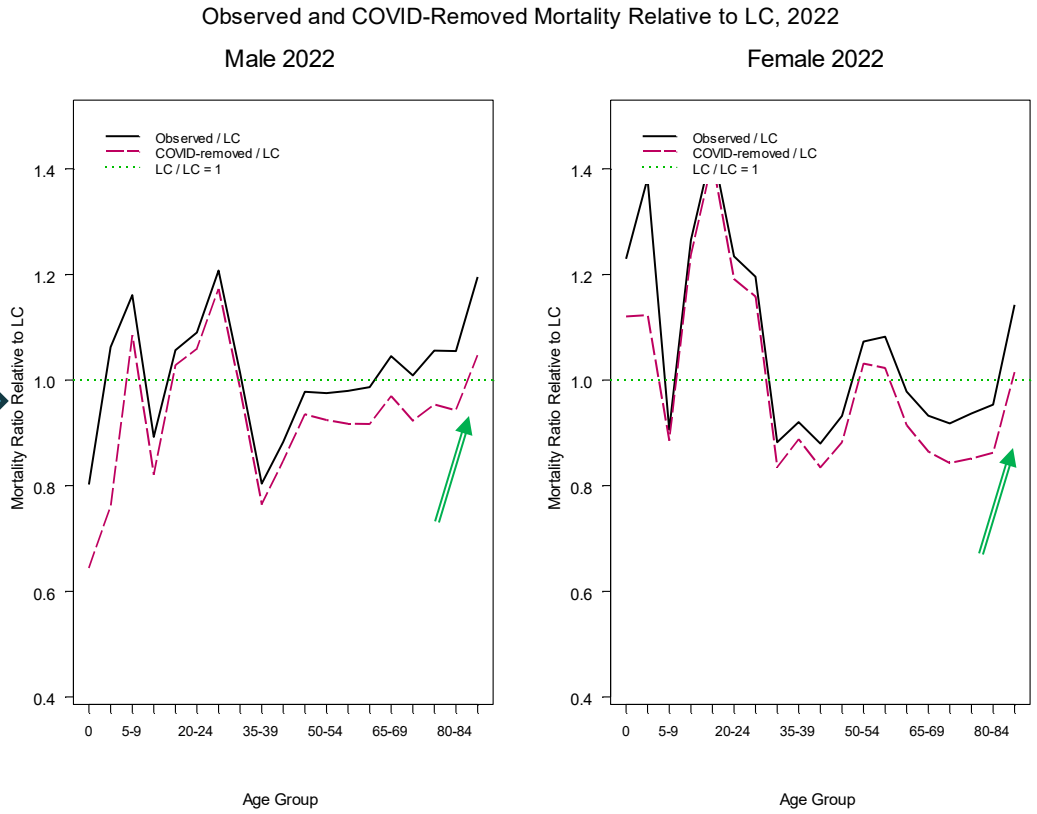


But are these estimated COVID deaths reasonable? Next, we check what happens after removing them.

LI: Does COVID Removal Move Mortality toward the Baseline?

- This figure compares mortality before and after removing estimated direct COVID deaths in 2022.
- The black line shows Observed/LC, the red line shows COVID-Removed/LC. The green line at 1 represents the LI no-COVID baseline.

- At many ages, the red line moves closer to 1 after COVID removal.
- The clearest result is at age 85+.
  Male: 1.195 → 1.003
  Female: 1.142 → 1.003
- After COVID removal, mortality at age 85+ is almost back to the baseline.

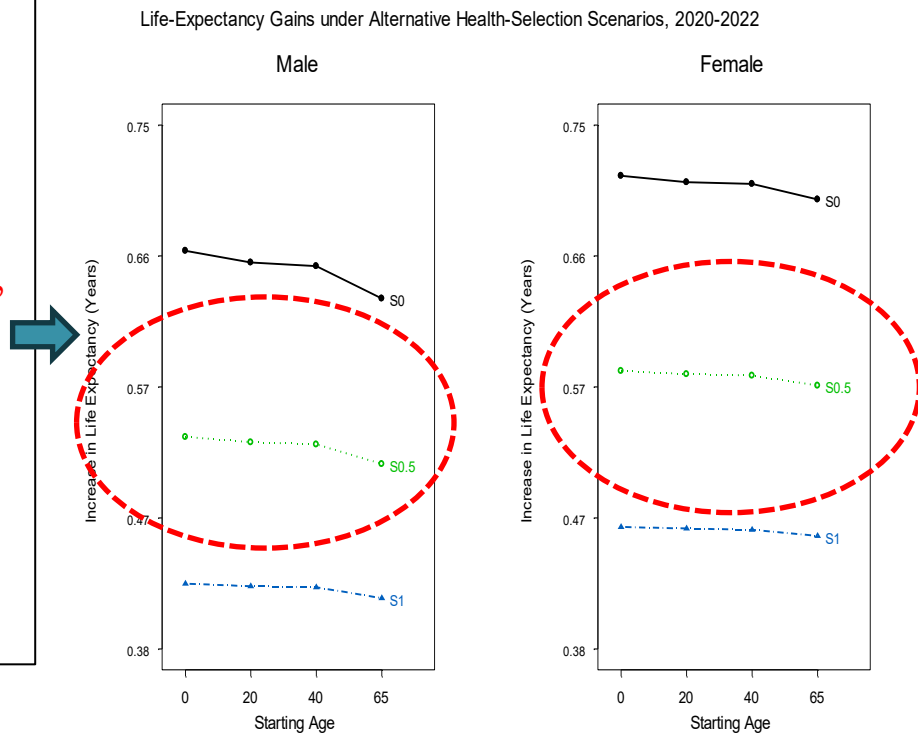


COVID removal moves mortality closer to the baseline. Next, we examine its effect on life expectancy.

LI: Life-Expectancy Gains after COVID Removal

- This figure shows the increase in life expectancy after removing estimated COVID deaths.
- Black solid line with filled circles: S0. Green dotted line with open circles: S0.5. Blue dash-dot line with triangles: S1.
- S0.5 is our central scenario. S0 and S1 show alternative health-selection assumptions; they are not confidence intervals.

- Under S0.5, life expectancy increases by about half a year for both males and females.
- The gain is slightly larger for females than for males.
- The life-expectancy gains at ages 0 and 65 are very similar. EX: male$\Delta e0 \approx 0.53$(Female:0.58), male$\Delta e65 \approx 0.51$(Female:0.57).
  - ➢ This suggests that much of the life-expectancy effect comes from mortality changes at older ages.
  - ➢ The similar gains at ages 0 and 65 suggest that older ages are important.



LI shows a sizable life-expectancy gain. Why is it larger than National?

Why Is LI Δe0 Larger Than National Δe0?

- The Figure: black line :National, green line : LI.
- Age:0–84, National and LI are very similar. The large difference appears mainly at age 85+.
- The table separates the total gain into the 0–84 and 85+ contributions.

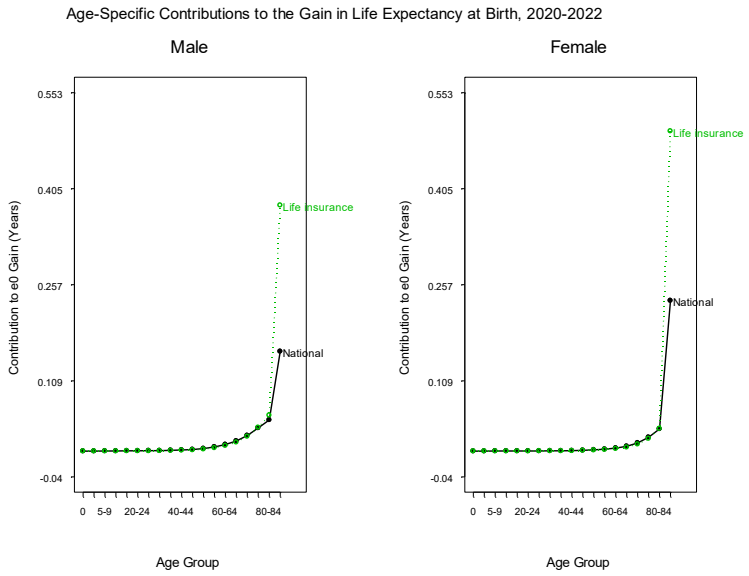
Male 0-84: National 0.155 vs. LI 0.150. Male 85+: National 0.154 vs. LI 0.379.

Female0-84 : National 0.091 vs. LI 0.083. Female 85+: National 0.232 vs. LI 0.494.

- The larger LI Δe0 comes mainly from age 85+. It does not mean that LI had higher COVID mortality at all ages.

Sex	Population	85+ share of Δe0 $(\%)\equiv\alpha=\frac{\beta}{\beta+\gamma}\times 100\%$	85+ contribution to Δe0 (years)≡β	0–84 contribution to Δe0 (years)≡γ
Male	National	49.82%	0.154	0.155
Male	LI	71.44%	0.379	0.150
Female	National	71.84%	0.232	0.091
Female	LI	85.65%	0.494	0.083

Δe0=0–84 contribution+85+ contribution



Next, we examine why the 85+ contribution is larger.

Why Is the LI 85+ Contribution Larger?

- We divide the 85+ contribution into two parts: Survivor effect: more people survive to age 85+. Mortality-rate effect: lower mortality after age 85. Both effects are larger in LI than in National. Male: survivor effect = 0.122 vs. 0.067; mortality-rate effect = 0.257 vs. 0.087. Female: survivor effect = 0.105 vs. 0.068; mortality-rate effect = 0.389 vs. 0.165.
- The mortality-rate effect is the larger part of the 85+ contribution. Male mortality-rate share: 56.24% in National and 67.76% in LI. Female mortality-rate share: 70.86% in National and 78.79% in LI.
- Therefore, the larger LI 85+ contribution reflects both stronger survivor and mortality-rate effects, with the mortality-rate effect contributing the larger share.

Sex	Population	Survivor Effect	Mortality-Rate Effect	Total 85+ Contribution	Mortality-Rate Share
Male	National	0.067	0.087	0.154	56.24%
Male	LI	0.122	0.257	0.379	67.76%
Female	National	0.068	0.165	0.232	70.86%
Female	LI	0.105	0.389	0.494	78.79%

Next, we summarize the main LI findings.

Note: $C_{85+} = C_{85+}^{\text{Survivor}} + C_{85+}^{\text{Mortality}}$

$C_{85+}^{\text{Survivor}} = \left(\frac{l_{85+}^{\text{Rem}} - l_{85+}^{\text{Obs}}}{l_0}\right)\left(\frac{1}{m_{85+}^{\text{Obs}}}\right)$ =More people reaching age 85+ × Life-years after age 85+

$C_{85+}^{\text{Mortality}} = \left(\frac{l_{85+}^{\text{Rem}}}{l_0}\right)\left(\frac{1}{m_{85+}^{\text{Rem}}} - \frac{1}{m_{85+}^{\text{Obs}}}\right)$ =People reaching age 85+ × Additional life-years after age 85+

l_x: survivors in the life table; m: mortality rate; Obs: observed; Rem: after COVID removal.

Life-Insurance Population: Summary

◆ 1. The largest mortality shock appeared in 2022.
Estimated direct COVID deaths were about 7,643 for males and 5,941 for females, accounting for 7.62% and 7.70% of observed deaths.

◆ 2. Positive direct COVID mortality could coexist with a negative residual.
Therefore, net excess mortality alone may understate the direct COVID component.

◆ 3. COVID removal improved the agreement with the LI no-COVID baseline.
In 2022, 12 of 19 age groups for both males and females returned to the historical LC forecast-error range. The result was especially clear at age 85+.

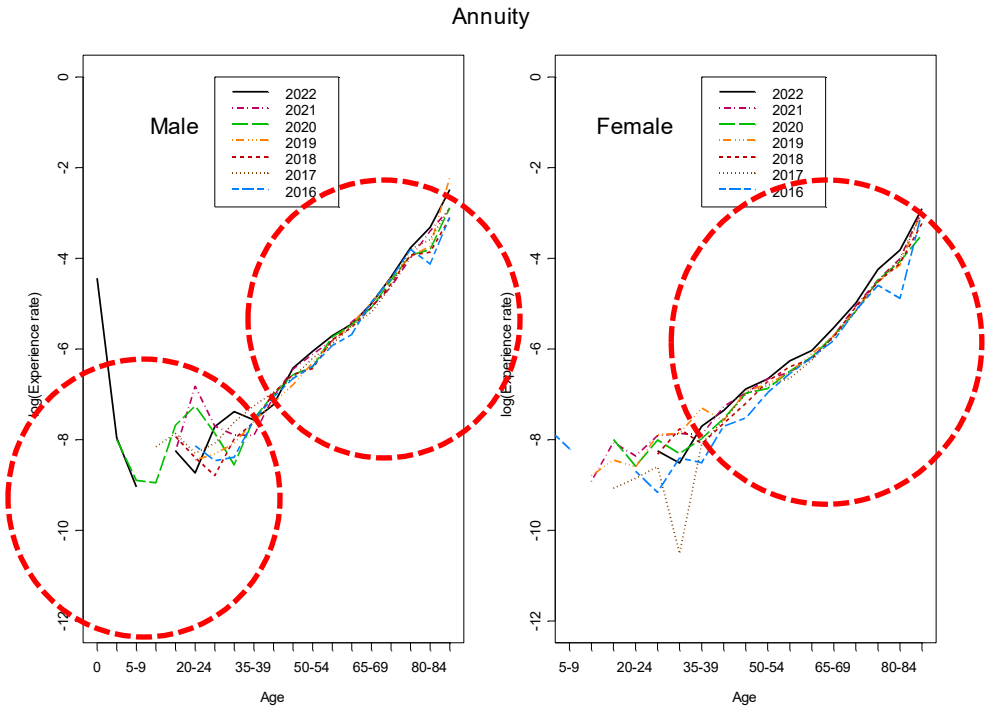
◆ 4. The larger LI life-expectancy gain came mainly from age 85+.
Both the survivor effect and the mortality-rate effect were larger in LI than in National. The mortality-rate effect had the larger share.

Next, we turn to the Annuity population.

Annuity Population: Empirical Analysis

Annuity Observed Mortality by Age, 2016–2022

- The figure focuses on 2016–2022 for comparison with the main shock year.
- We first look at the observed Annuity mortality patterns.
- Annuity mortality shows more year-to-year variation than National and LI mortality.
- The variation is especially clear at some younger ages.
- At older ages, the mortality pattern becomes more stable and generally rises with age.
- In 2022, observed mortality is generally higher after about age 40 for both males and females.
- The short data period and larger variation make long-term mortality estimation more difficult.

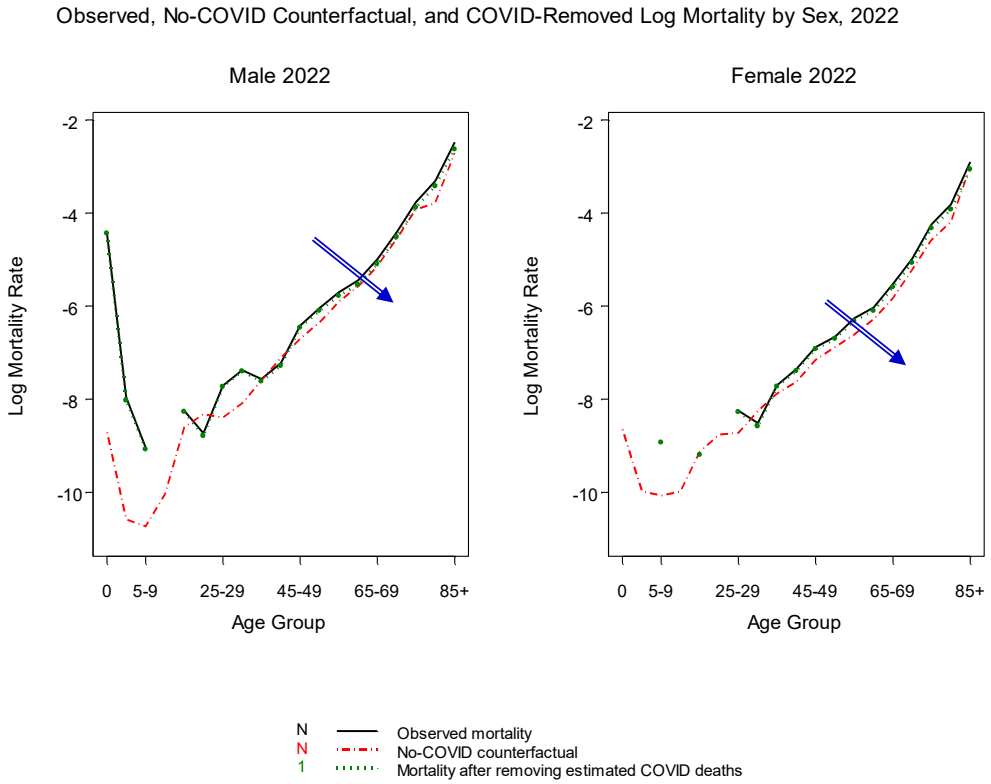


Next, we compare observed mortality with the Annuity no-COVID baseline.

Annuity: Observed, No-COVID, and COVID-Removed Mortality in 2022

- This figure compares observed, no-COVID, and COVID-removed log mortality in 2022.
- The black solid line shows observed mortality, the red dashed line shows the Annuity no-COVID baseline, and the green line with points shows mortality after removing estimated direct COVID deaths.

- At many middle and older ages, observed mortality is above the no-COVID baseline.
- After COVID removal, the green line generally moves toward the red baseline, but some gaps remain.
- Therefore, estimated direct COVID deaths explain part, but not all, of the gap from the no-COVID baseline.



Some gaps remain after COVID removal. Next, we compare excess deaths with estimated direct COVID deaths.

Annuity: Excess Mortality and Estimated Direct COVID Deaths

- This table compares excess mortality with estimated direct COVID deaths from 2020 -23.
- Relative Excess Mortality (REM) increased sharply in 2022 and remained high in 2023. In 2022, female REM is 33.08%, compared with 21.53% for males.
- However, estimated direct COVID deaths under S0.5 were almost the same for males and females in 2022: 292 vs. 295. Excess deaths were 570 vs. 994. This suggests a larger residual component for females.

Note: For males, the residual is about 278=570−292 deaths. For females, it is about 699=994−295 deaths

- From 2022 to 2023, the estimated direct-COVID share of excess deaths decreased. It fell from 51.33% to 32.58% for males and from 29.68% to 19.65% for females, while REM remained high.
- Excess mortality was highest in 2022, while the residual remained high in 2023.

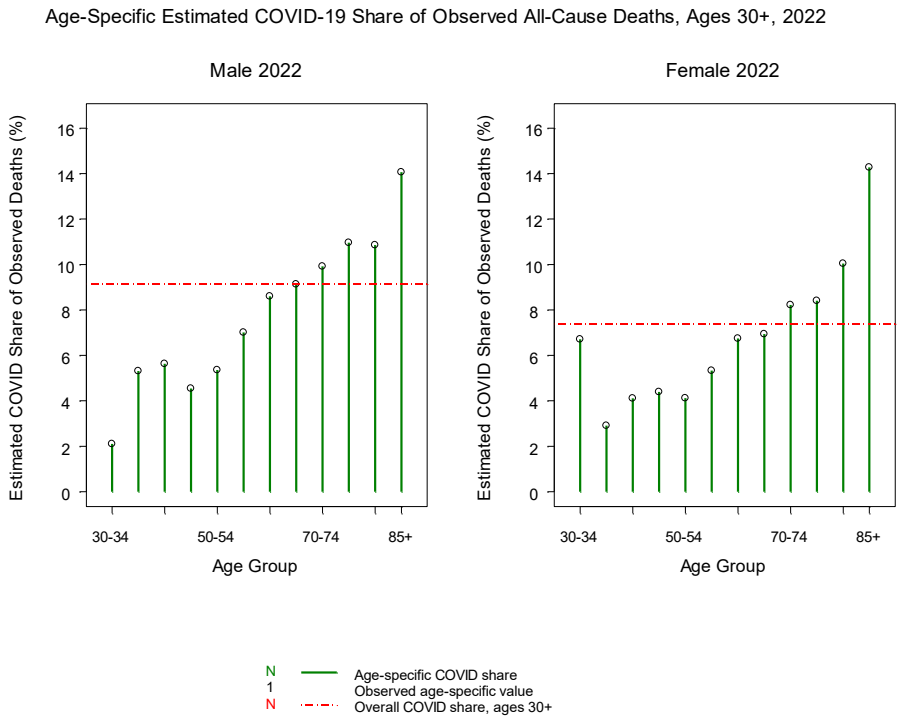
Sex	Year	Excess deaths	REM %	S0.5 COVID	COVID Share of Excess
Male	2020	56	2.60%	—	—
Male	2021	159	6.26%	28	17.70%
Male	2022	570	21.53%	292	51.33%
Male	2023	530	20.26%	173	32.58%
Female	2020	88	3.53%	—	—
Female	2021	353	12.29%	26	7.34%
Female	2022	994	33.08%	295	29.68%
Female	2023	892	29.74%	175	19.65%

Next, we examine how the direct COVID share differs by age.

Annuity: Age-Specific Direct COVID Share in 2022

- This figure shows the estimated direct COVID share of observed deaths by age in 2022.
- Green stems show the age-specific COVID share. The red dash-dot line shows the overall share for ages 30+.

- Under S0.5, the overall share is about 9.09% for males and 7.38% for females.
- The COVID share generally increases with age. The highest shares appear at older ages, especially age 85+.
- The share is a little higher for males, but the age patterns are similar.

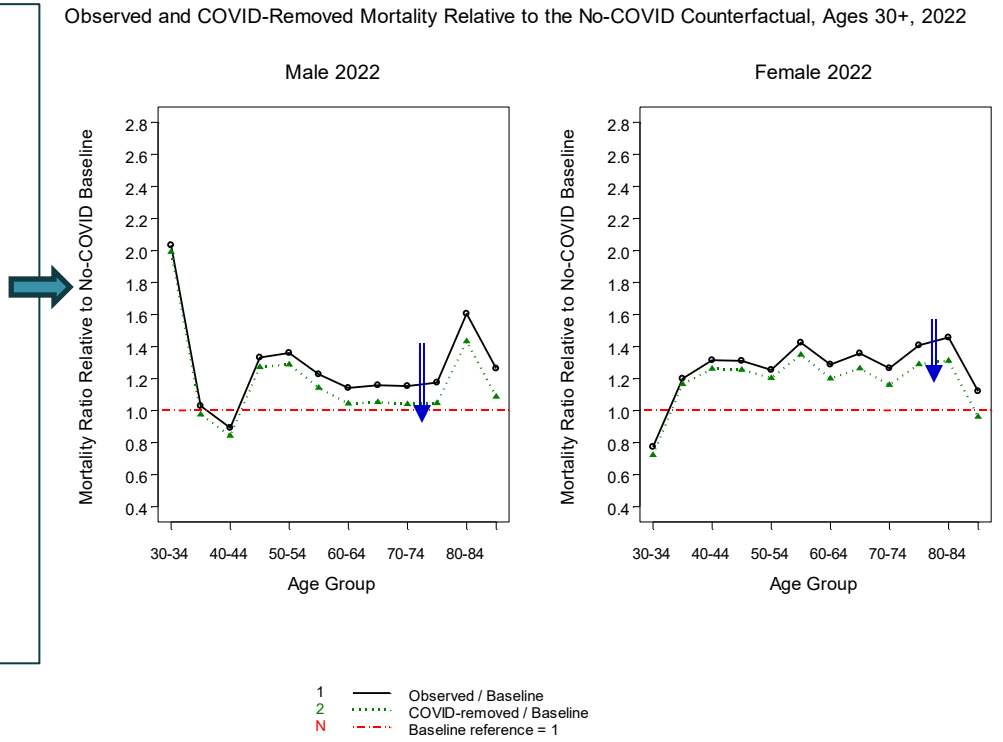


Next, we check whether COVID removal moves mortality closer to the no-COVID baseline.

Annuity: COVID-Removal Validation in 2022

- This figure compares mortality before and after removing estimated direct COVID deaths.
- Black circles and solid lines show Observed/Baseline. Green triangles and dashed lines show COVID-Removed/Baseline. The red horizontal line at 1 represents the no-COVID baseline.

- After COVID removal, 11 of 12 age groups aged 30+ move closer to the baseline for both males and females.
- All five age groups aged 65+ move closer.
- For females aged 85+, the ratio moves from 1.120 to 0.960. It crosses below 1, but still moves closer to the baseline.
- Overall, COVID removal moves mortality closer to the baseline at most ages. However, some gaps remain.



What explains the remaining gap? Next, we separate excess deaths into direct COVID and residual components.

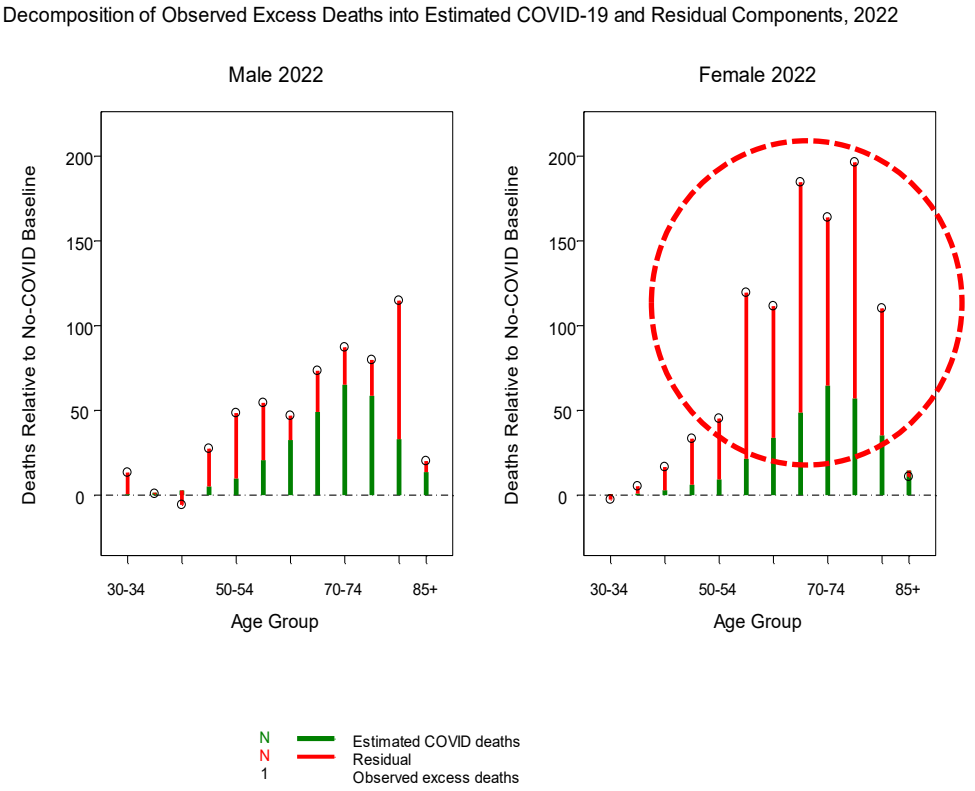
Annuity: Direct COVID and Residual Excess Deaths

- We divide excess deaths into two parts: estimated direct COVID deaths and the residual.

$$D_{x,t}^{\text{Excess}} = \hat{D}_{x,t}^{\text{COVID}} + D_{x,t}^{\text{Residual}}$$

- Green stems show estimated direct COVID deaths. Red segments show the residual. Open circles show total excess deaths.

- In 2022, estimated direct COVID deaths are important at middle and older ages, but the residual is also large, especially for females.
- A negative residual does not mean negative COVID deaths. It means that estimated direct COVID deaths are larger than observed net excess deaths.
- The difference between excess deaths and estimated direct COVID deaths is the residual.



Next, we aggregate these components by sex and compare 2022 with 2023.

Annuity Excess-Death Decomposition in 2022–2023

- In 2022, male excess deaths were 569.69: 292.40 estimated direct COVID-19 deaths and 277.29 residual deaths. Estimated COVID deaths accounted for 51.33% of excess deaths. For females, excess deaths were much higher at 994.32, although estimated direct COVID-19 deaths were similar at 295.14. The residual was 699.18.
- The female residual in 2022 was about 2.5 times the male residual, despite nearly identical estimated direct COVID-19 deaths.
- From 2022 to 2023, estimated direct COVID-19 deaths decreased substantially, while the residual increased—from 277.29 to 357.51 for males and from 699.18 to 716.63 for females.
- This large residual is an important finding and needs further study with more data.

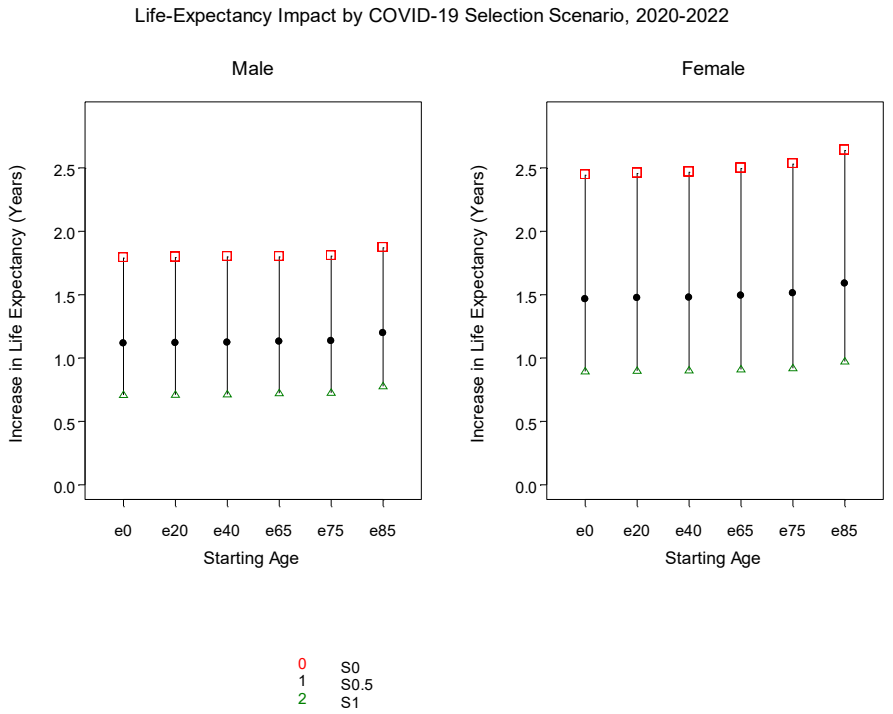
Sex	Year	Excess Deaths	Estimated COVID Deaths	Residual Deaths	COVID Share of Excess (%)
Male	2022	569.69	292.40	277.29	51.33%
Male	2023	530.29	172.79	357.51	32.58%
Female	2022	994.32	295.14	699.18	29.68%
Female	2023	891.94	175.31	716.63	19.65%

Next, we examine its effect on life expectancy.

Annuity: Life-Expectancy Impact under Health-Selection Scenarios

- This figure shows how much life expectancy increases after removing the estimated direct COVID-19 mortality under three health-selection scenarios: S0, S0.5, and S1, for 2020–2022.
- The red open squares represent S0 (no adjustment), the black filled circles represent S0.5 (partial adjustment), and the green open triangles represent S1 (full adjustment).

- Under the central S0.5 scenario, the gain is 1.1164 years at birth and 1.1305 years at age 65 for males. For females, the corresponding gains are larger: 1.4654 years and 1.4933 years.
- The e_0 and e_{65} gains are very close, This suggests that older ages are important.
- Females show larger life-expectancy gains than males across all starting ages.



However, the size of these gains may depend on the pooling period. Next, we examine this sensitivity.

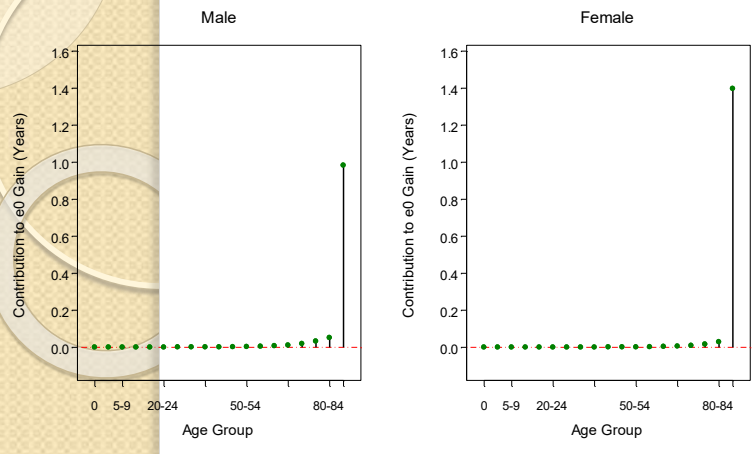
Annuity Life-Expectancy and Pooling Sensitivity

- Adding 2018–2019 to the pooling period reduces the life-expectancy gains.(**see next slide**) Male Δe_0 falls from 1.1164 to 0.7428 years, and female Δe_0 from 1.4654 to 1.1332 years.
- The size of the gain depends on the pooling period, but the gain remains positive
- For both sexes and both pooling periods, the gain increases slightly with starting age, and Δe_{85} is the largest.

Sex	Pooling period	Δe_0	Δe_{65}	Δe_{85}
Male	2020–2022	1.1164	1.1305	1.1973
Male	2018–2022	0.7428	0.7497	0.7821
Female	2020–2022	1.4654	1.4933	1.5880
Female	2018–2022	1.1332	1.1571	1.2378

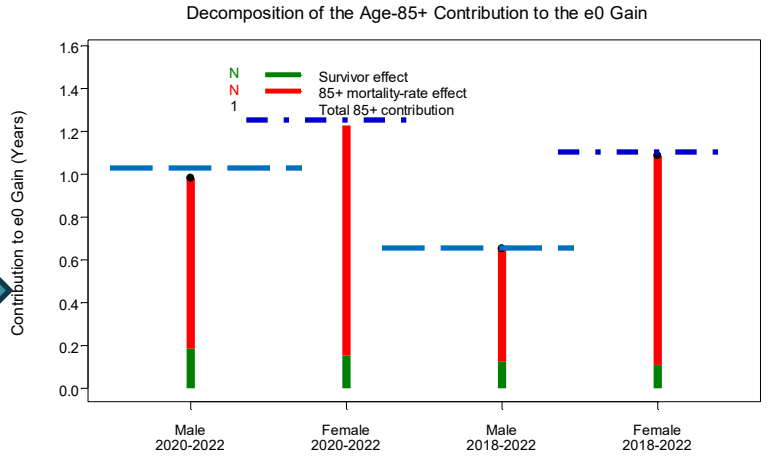
Why is the annuity life-expectancy gain so large?
Next, we examine the contribution by age.

Why Is the Annuity Life-Expectancy Gain So Large?



- The upper figures show how each age group contributes to the gain in life expectancy at birth (Δe_0).
- Most age groups have small effects, but age 85+ has a much larger effect.
- Therefore, **the large annuity Δe_0 comes mainly from age 85+.**

- In the lower figure, the green part is the survivor effect, **the red part is the mortality-rate effect**, and the black point is the total effect.
- The mortality-rate effect is much larger than the survivor effect. This means that the large 85+ contribution comes mainly from the lower 85+ mortality rate after COVID removal.
- The same pattern is seen for both pooling periods, although the effect is smaller for 2018–2022.



Next, we summarize the main findings for the annuity population.

Annuity Population: Summary

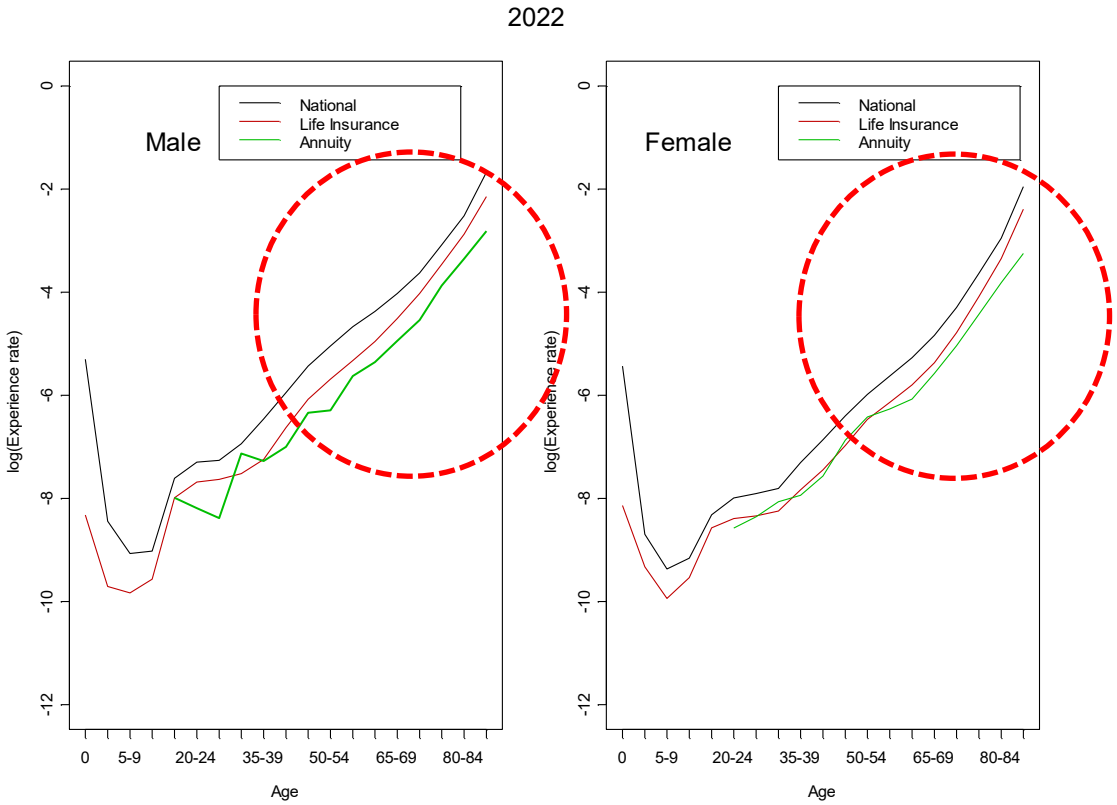
- Direct COVID-19 deaths are estimated using National COVID mortality, annuity exposure, and the health-selection adjustment s(x). The annuity no-COVID baseline is constructed separately using the LI long-term mortality trend and the annuity mortality level.
- The annuity mortality shock was largest in 2022 and remained high in 2023. In 2022, Relative Excess Mortality (REM) was higher for females than for males (33.08% vs. 21.53%).
- Estimated direct COVID-19 deaths were almost the same for females and males in 2022 (295.14 vs. 292.40), but the female residual was about 2.5 times the male residual (699.18 vs. 277.29). **So the large sex difference in 2022 comes mainly from the residual, not estimated direct COVID deaths.**
- After COVID removal, 11 of 12 age groups aged 30+ and all 5 age groups aged 65+ moved closer to the no-COVID baseline for both sexes.
- The large life-expectancy gain comes mainly from age 85+, especially from the mortality-rate effect. Therefore, a larger life-expectancy gain does not necessarily mean higher COVID mortality risk**.**

We have now examined each population separately. Next, we compare National, Life Insurance, and Annuity.

National vs. Life Insurance vs. Annuity

Observed Mortality across Three Populations in 2022

- This figure compares observed mortality across the three populations in 2022.
- Black: National. Red: Life Insurance. Green: Annuity.



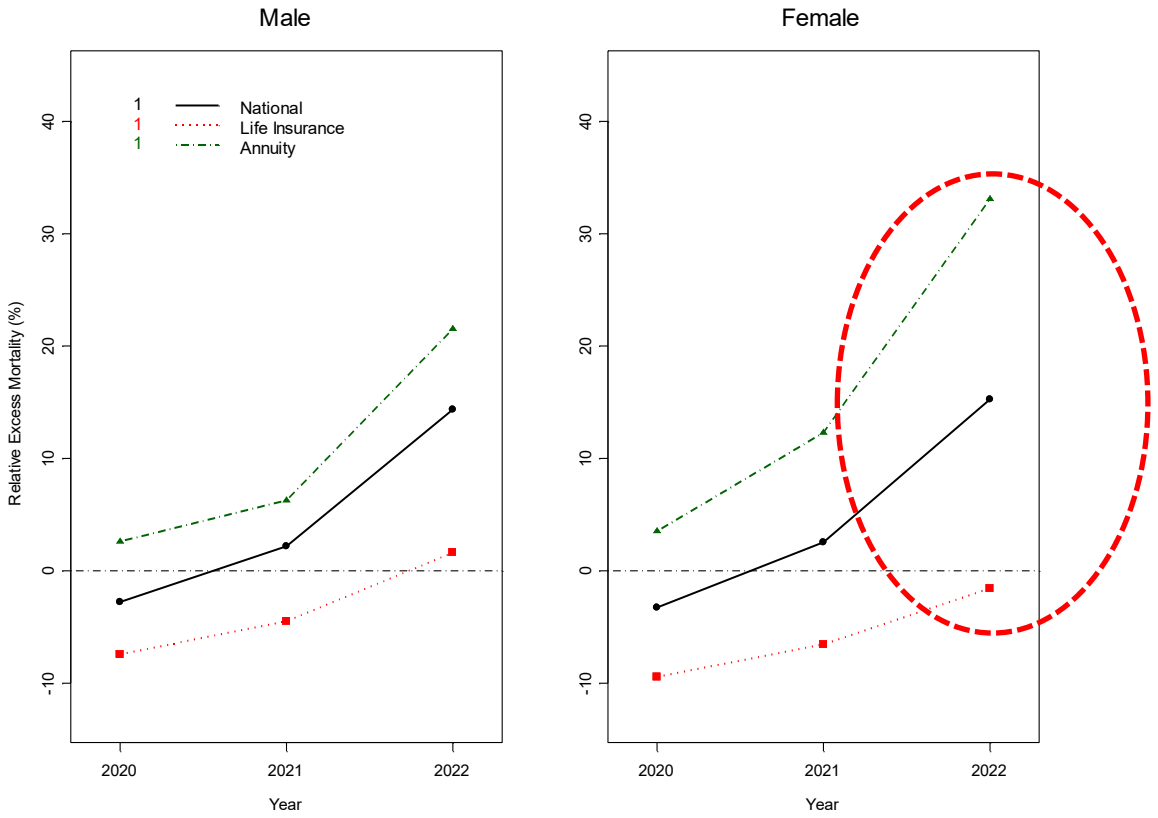
- The three populations have similar age patterns, but different mortality levels.
- Annuity has lower mortality at many ages.
- However, lower mortality does not mean a smaller mortality shock.
- The mortality shock must be measured against each population's own no-COVID baseline.

Next, we compare REM across the three populations.

Three-Population Relative Excess Mortality (REM)

- Black =the National population. Red =Life Insurance (LI). Green =Annuity
- In 2022, male REM was 14.36% for National, 1.62% for LI, and 21.53% for Annuity.
- The largest difference appears among females: 15.25% for National, −1.57% for LI, and 33.08% for Annuity.
- Therefore, the three populations show very different mortality shocks, especially for females.

- National: The mortality shock becomes positive in 2021 and rises sharply in 2022.
- LI: REM remains relatively low.
- Annuity: REM is already positive in 2020 and rises strongly by 2022.



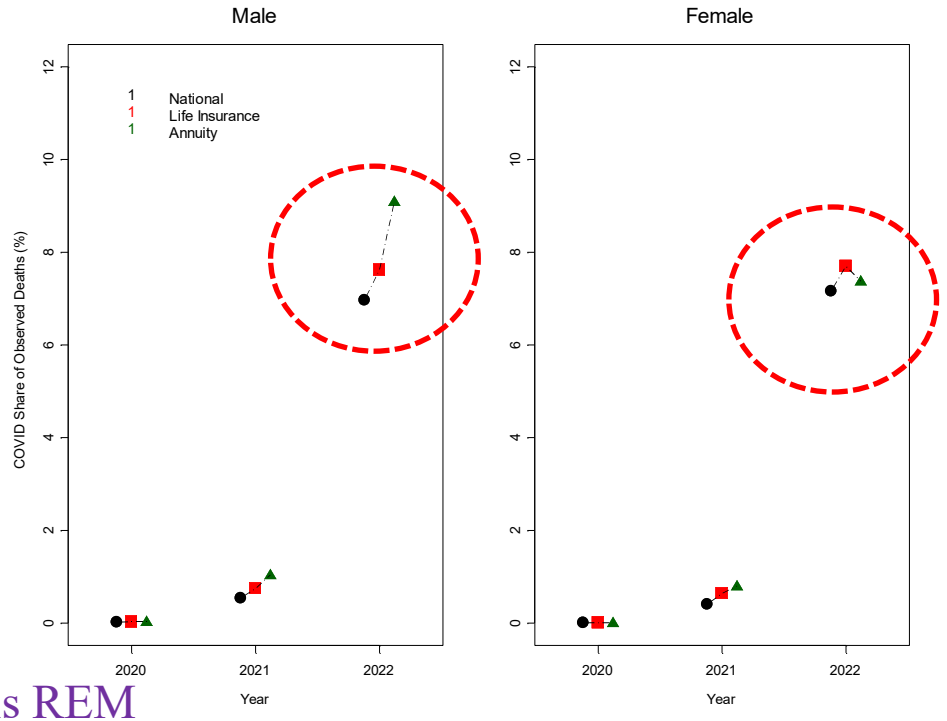
REM differs greatly. Is the direct COVID share also different?

Direct COVID-19 Share of Observed Deaths

- COVID share is the estimated direct COVID deaths divided by observed deaths.
- In 2022, the male shares were 6.96% for National, 7.62% for LI, and 9.09% for Annuity.
- Female shares were even closer: 7.16% for National, 7.70% for LI, and 7.38% for Annuity.
- Therefore, **direct COVID shares are relatively similar**, although **REM differs greatly** across the three populations, especially for females.(on the previous slide)
- This suggests that the large differences in total mortality shock are mainly related to the residual component, not direct COVID deaths alone.

2022 Direct COVID Burden Share

Sex	National	LI	Annuity
Male	6.96%	7.62%	9.09%
Female	7.16%	7.70%	7.38%



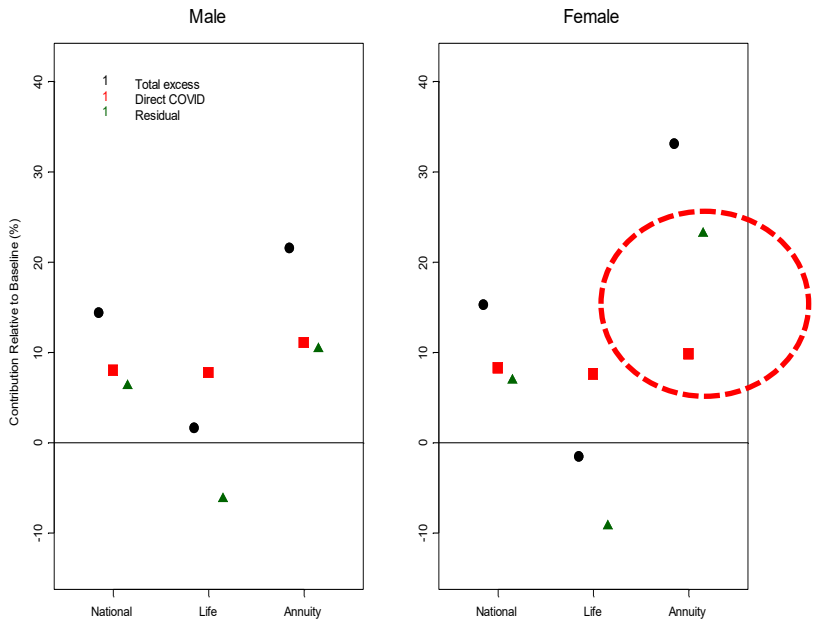
The COVID shares are similar. So why is REM so different?

Three Different Mortality-Shock Patterns in 2022

- This figure divides the total mortality shock into direct COVID and residual components.
- Black circles show total excess mortality, red squares show direct COVID, and green triangles show the residual.
- The three populations show different patterns:
  - National = positive direct-COVID + positive residual; LI = positive direct-COVID + negative residual; and Annuity = positive direct-COVID +positive residual
- The difference is especially large for females. LI has a negative residual (−9.1%), while Annuity has a large positive residual (23.3%).
- Therefore, the large differences in total mortality shock are mainly related to the residual component, not direct COVID alone.

Sex	Population	Total excess (%)	Direct COVID(%)	Residual(%)
Male	National	14.4	7.96	6.4
Male	LI	1.6	7.74	−6.1
Male	Annuity	21.5	11.05	10.5
Female	National	15.3	8.25	7.0
Female	LI	−1.57	7.57	−9.1
Female	Annuity	33.1	9.82	23.3

Note: Unlike the previous slide, all percentages here use expected deaths as the denominator, so Total Excess = Direct COVID + Residual.



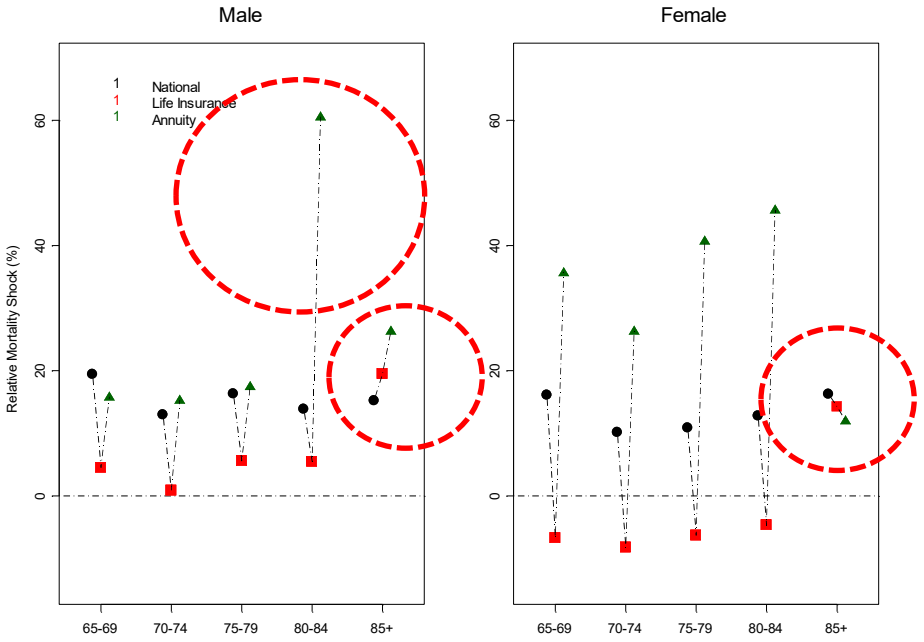
Next, let's see how the shocks differ at older ages.

Mortality Shocks at Older Ages in 2022

- This figure compares relative mortality shocks at ages 65+ across the three populations.
- Black circles represent National, red squares represent LI, and green triangles represent Annuity. The dashed horizontal line represents zero excess mortality.
- For males aged 65–79, LI has the smallest mortality shock. **At age 80–84, Annuity rises sharply to 60.58%.**
- For females aged 65–84, the pattern is very clear: National is positive, LI is negative, and Annuity is strongly positive.
- The female Annuity–LI difference is more than 34 percentage points at every age from 65-84
- This difference becomes smaller at age 85+

2022 Age-Specific Relative Mortality Shocks (%)

Age	Nat. M	LI M	Ann. M	Nat. F	LI F	Ann. F
65–69	19.45	4.53	15.81	16.11	−6.74	35.67
70–74	12.97	0.86	15.32	10.16	−8.23	26.35
75–79	16.34	5.57	17.51	10.87	−6.32	40.74
80–84	13.87	5.49	60.58	12.81	−4.66	45.70
85+	15.23	19.51	26.34	16.26	14.24	12.04



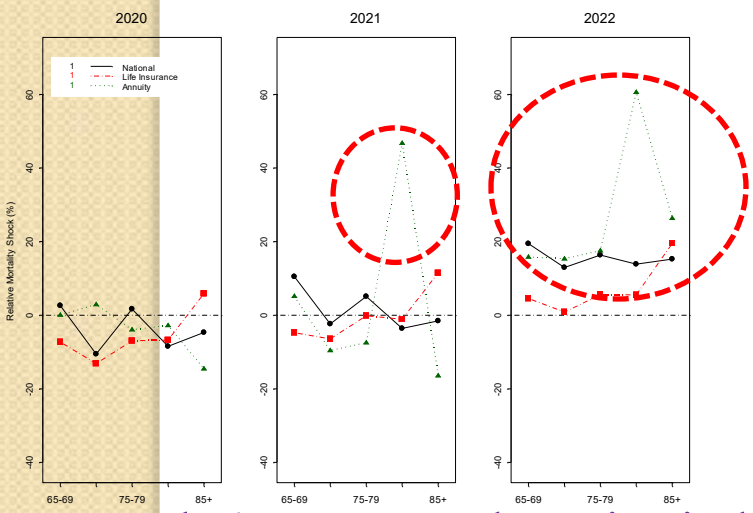
These differences are clear in 2022. But when did they begin?

How Did Older-Age Mortality Shocks Change Over Time?

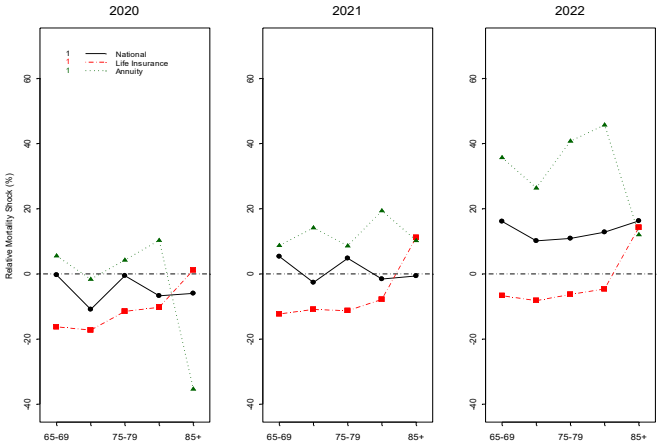
- The panels compare mortality shocks at ages 65+ from 2020 to 2022. Black = National, red = LI, and green = Annuity.
- National: Mortality shocks spread to more older age groups and become clearly positive by 2022.
- LI: Mortality shocks stay relatively low. The earlier negative pattern becomes weaker over time.
- Annuity: Positive shocks appear earlier in some older age groups and become much larger by 2022, especially for females.
- By 2022, Annuity shows larger positive shocks, while LI remains relatively low.

Note: Mortality shock > 0: Observed mortality > No-COVID mortality

Male: 2020 → 2021 → 2022



Female: 2020 → 2021 → 2022



Next, let's compare the gains in life expectancy.

Life Expectancy Gains After COVID-19 Removal

- We pool deaths and exposures over 2020–2022 to construct period life tables for National, LI, and Annuity. LI and Annuity use the S0.5 central scenario.
- $\triangle e_x = e_x^{Rem} - e_x^{Obs}$ measures the increase in life expectancy after removing the estimated direct COVID-19 deaths.
- For males $\triangle e_0$ is 0.3090 years in National, 0.5309 in LI, and 1.1164 in Annuity. For females, the corresponding gains are 0.3234, 0.5765, and 1.4654 years.
- The ordering Annuity > LI > National holds for both e_0 and e_{65}. Females generally show larger gains than males.
- However, a larger Δe does not necessarily mean higher direct COVID-19 mortality risk. The life-expectancy gain also depends on the ages at which mortality changes occur

Sex	Starting age	National (△e)	LI (△e)	Annuity (△e)
Male	e_0	0.3090	0.5309	1.1164
Male	e_{65}	0.2814	0.5121	1.1305
Female	e_0	0.3234	0.5765	1.4654
Female	e_{65}	0.3064	0.5663	1.4933

Why is the gain larger for Annuity?

Why Does Annuity Have a Larger Life-Expectancy Gain?

- Lower mortality does not mean a smaller life-expectancy gain.
- The life-expectancy gain depends on where mortality changes occur, not only on the mortality level.
- For Annuity, most of the gain comes from age 85+.

$$L_{85+} = \frac{l_{85}}{m_{85+}}$$

- When m_{85+} falls, L_{85+} can increase strongly. This makes life expectancy very sensitive to mortality changes at age 85+.

Note: Age 85+ is an open-ended age group. l_{85} is the number of survivors reaching age 85, m_{85+} is the mortality rate at age 85+, and L_{85+} is the total person-years lived after age 85

- This table shows the share of the total e_0 gain that comes from age 85+. It is not the share of COVID-19 deaths
- EX: For males, the 85+ share increases from about 50% in National to 71% in LI and 88% in Annuity
- For females, it increases from about 72% to 86% and 95%. Therefore, the Annuity life-expectancy gain is highly concentrated at age 85+

	85+ share of Δe_0	
Male	National	49.82%
	LI	71.44%
	Annuity	88%
Female	National	71.84%
	LI	85.65%
	Annuity	95.30%

What may explain these population differences?

Possible Reasons for the Population Differences

- Health selection: LI and Annuity generally have lower mortality than National. A lower baseline can make a relative mortality shock look larger.
- The 85+ effect mainly comes from the mortality-rate effect, not simply from more people surviving to age 85. For Annuity, the mortality-rate effect accounts for about 81% of the male and 89% of the female 85+ contribution.
- Changes in selection effect: The mortality advantage may have changed during the COVID period.
- Residual mortality may have several causes: non-COVID mortality changes, population-composition changes, or estimation error may all contribute.
- The 85+ open-age group has a large effect on the estimated life-expectancy gain. Therefore, a larger Δe_0 does not necessarily mean higher direct COVID-19 mortality.

However, our data cannot fully explain these differences.

Study Limitations

- National COVID-19 deaths are observed data, but COVID-19 deaths for LI and Annuity are estimated. Their results therefore depend on the estimation method and scenario.
- The Annuity data cover only 2016–2023. The short period limits long-term mortality analysis.
- The three populations have different age structures and mortality levels. Therefore, direct comparison should be made with care.
- The 85+ open-age group has a large effect on life expectancy. Results for $\Delta e0$ and $\Delta e65$ are therefore sensitive to mortality at age 85+.
- More post-pandemic data are needed to determine whether the 2022 mortality shock was temporary or long-lasting.

Even with these limitations, the findings are useful for future annuity life tables.

Implications for Future Annuity Life Tables

- **The full 2022 shock should not be treated as a long-term trend**. More data are needed to see whether it continues.
- Direct COVID deaths for LI and Annuity are estimated, not observed. Therefore, S0.5 should be interpreted together with S0 and S1.
- Residual mortality should not automatically be interpreted as indirect COVID mortality.
- The 85+ age group needs special attention because it has a large effect on the estimated life-expectancy gain..
- For practical life-table construction, the observed annuity mortality experience can still be used after graduation. If insurers want a safer assumption, they may add a mortality margin.

Finally, let us summarize the main findings.

Conclusions

- COVID-19 mortality shocks differed across National, LI, and Annuity, by year and age.
- Estimated direct COVID deaths alone cannot explain the large differences in mortality shock across the three populations, especially for females.
- In 2022, the residual is an important difference: positive in National, negative in LI, and strongly positive in Annuity, especially for females.
- Removing direct COVID deaths increases life expectancy, but much of the gain comes from age 85+. Therefore, a larger gain does not mean higher direct COVID mortality risk.

Finally, these are our main conclusions.

Thank you for your attention.