The Evolving Dynamics of Covid-19: Lessons For Mortality Risk Measurement and Management

Andrew J.G. Cairns

Heriot-Watt University, Edinburgh

2022 Virtual ASTIN AFIR/ERM Colloquia, June 21-23

Agenda

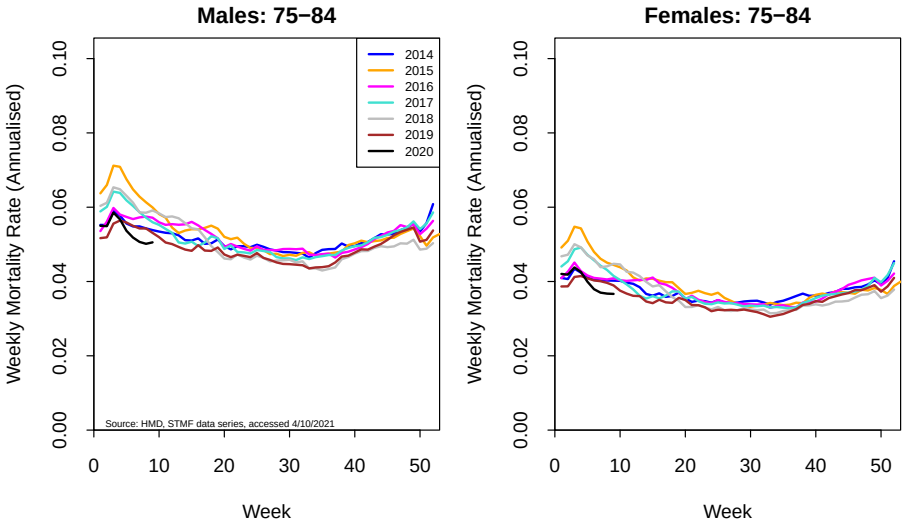
- Objectives
- Demographics of the Covid-19 victims
  - What is the relationship between Covid mortality and all-cause mortality?
  - What do we know about infection rates?
  - What has the impact of vaccination and new variants been?
- What is the impact on mortality catastrophe bonds?
- Rethinking future extreme scenarios

Focus on English data.
But many conclusions will apply to other countries.

Objectives of Our Work

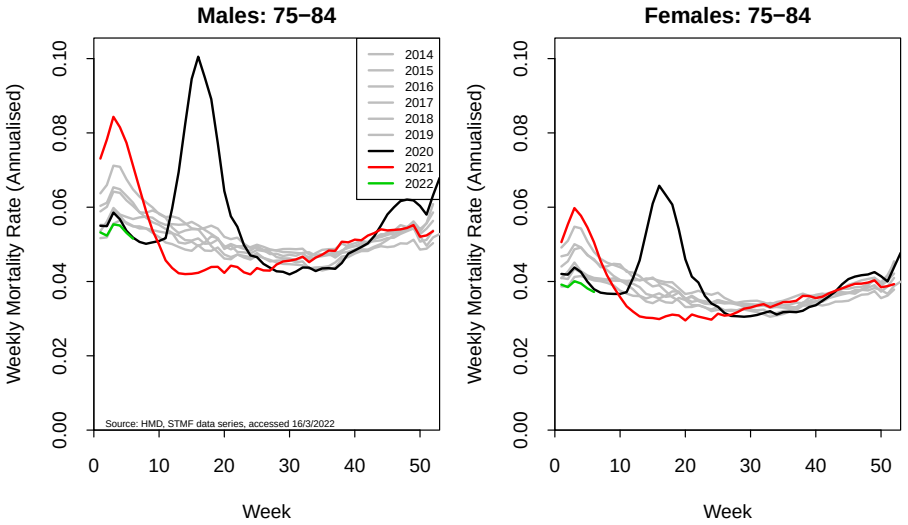
- What does the mixture of people dying from Covid-19 look like?
  - e.g. age profile, deprivation, region
- How has this changed during the course of the pandemic?
- What was the impact of vaccinations and new variants?
- Is the level of Covid-19 mortality inequality different from the level of all-cause mortality inequality in 'normal' years?
- Are index-based mortality catastrophe bonds fit for purpose?
- Do we need to revise our catalogue of extreme mortality scenarios?

English Weekly Mortality Rates 2014 to March 2020



Source data: www.mortality.org (STMF data series, accessed 16/3/2022)

2020-22 in Context: English Weekly Mortality Rates Since 2014

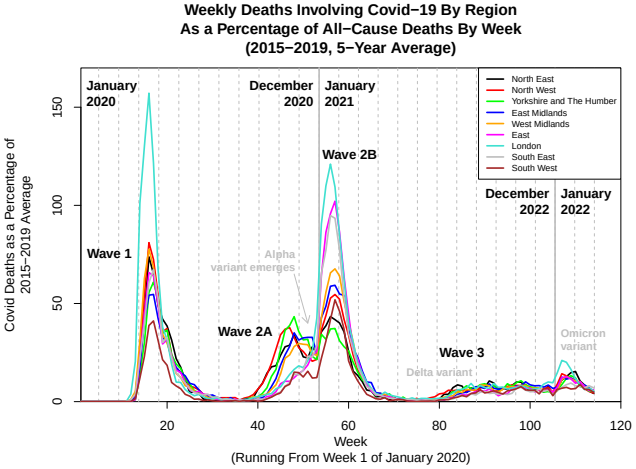


Variation By Region

North East
North West
Yorkshire & Humber
East Midlands
West Midlands
East of England
London
South East
South West

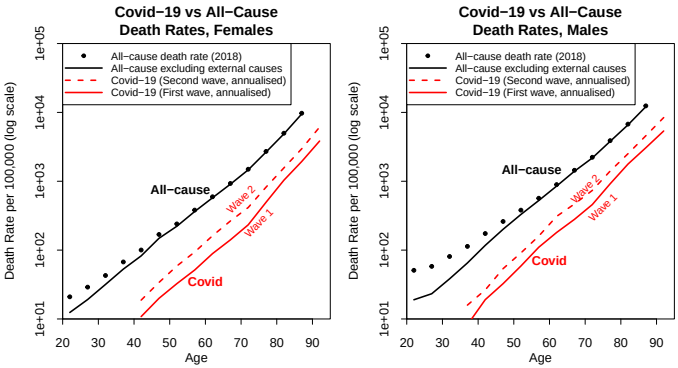
Not in dataset:
Scotland, Wales,
Northern Ireland

Weekly Covid-19 Death Rates: 2020/21 by English Region



- Considerable variation between regions
- More variation around Europe
- Wave 1:
  - London leads, but similar timing
  - Very different magnitudes
- Wave 2:
  - Wave 2A more focused in the northern regions
  - Wave 2B stronger in the south
- London Covid death rates 170% higher than the South West

Covid-19 Death Rates, Waves 1 and 2 (up to January 2021)



(Adapted from a David Spiegelhalter blog)

- Death rates are on a logarithmic scale
- All cause: with and without external causes
- Waves 1, 2 and 2018-all-cause are almost parallel!
- Waves 1 & 2: very similar age profile
- Conclusion: Covid death rates by age are approximately proportional to all-cause mortality (excluding external causes).

Provisional Takeaway: The Proportionality Hypothesis

The comparison with all-cause death rates suggests the following way to look at Covid-19 mortality for age x:

$$\text{Covid Mortality Rate}(x) = \text{all-cause mortality rate}(x) \times \text{infection rate}(x) \times \text{relative frailty}(x)$$

- "Relative Frailty" measures the probability of death from Covid-19 (if infected) *relative to* the annual probability of death from all causes.
- The graphic suggests that infection rate(x) $\times$ relative frailty(x) changes only slowly with age

Generalising the *proportional to all-cause mortality* concept

Individuals aged x, have varying levels of 'frailty':

- Data $\Rightarrow$ variation by sub-group (e.g. mortality varies considerably by deprivation/wealth/affluence/education); the result of variation in
  - individual risk factors (e.g. smoking, poor diet, exercise, ...)
  - individual state of health

General observation about Covid-19: if infected

- Older people are more at risk
- People who have more co-morbidities *than the average for their age group* are more at risk

Generalising this concept by group

Group i

$$\text{Covid Mortality Rate}(i,x) = \text{All-cause mortality rate}(i,x) \times \text{infection rate}(i,x) \times \text{relative frailty}(i,x)$$

where group i might be characterised by e.g.
region; urban/rural; neighbourhood deprivation; ethnic group; ...

Hypothesis: relative frailty(i,x) does not vary much by age or sub-group

i.e. differences in Covid-19 mortality between groups are largely due to differences in all-cause mortality and in infection rates

How to verify if this is true?

Infection rates

$$\text{Covid Mortality Rate}(i,x) = \text{All-cause mortality rate}(i,x) \times \text{infection rate}(i,x) \times \text{relative frailty}(i,x)$$

Infection rates: antibody prevalence data following the first wave $\Rightarrow$

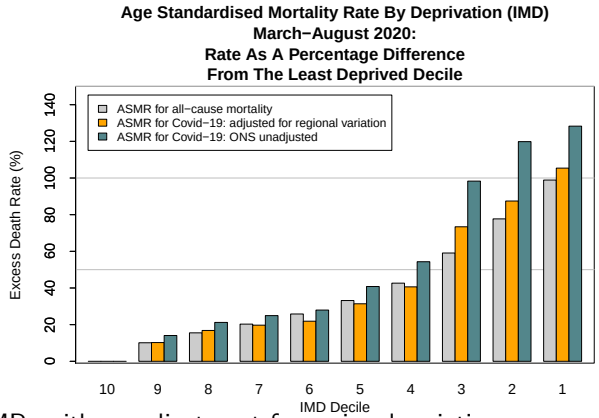
- About 6% of adults were infected
- Relatively little variation by age and sex
- Relatively little variation by deprivation (Index of Multiple Deprivation, IMD)
- Significant variation by region (e.g. London $>>$ South West)

Mortality Rates

$$\text{Covid Mortality Rate}(i,x) = \text{All-cause mortality rate}(i,x) \times \text{infection rate}(i,x) \times \text{relative frailty}(i,x)$$

- Data: Age Standardised Mortality Rates (ASMR) by deprivation decile
- Data: Age Standardised Mortality Rates by region
- But: ASMR by deprivation decile is distorted by regional effects (e.g. London more deprived and higher infection rates)
- ASMR by region allows us to adjust the ASMR by deprivation decile

ASMRs by deprivation: Wave 1, Adjusted for Regional Variation

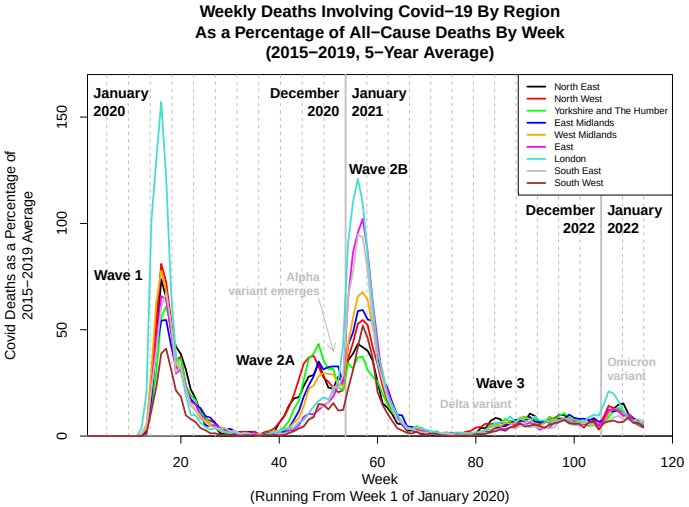


- Blue bars: ASMRs with no adjustment for regional variation
- **Orange bars: ASMRs with the effect of regional variation filtered out**
- Covid-19 ASMRs by decile are now approximately proportional to all-cause ASMRs
- Conclusion: Relative Frailty(i, x) varies very little across deprivation deciles $i = 1, ..., 10$

Further plots and analysis

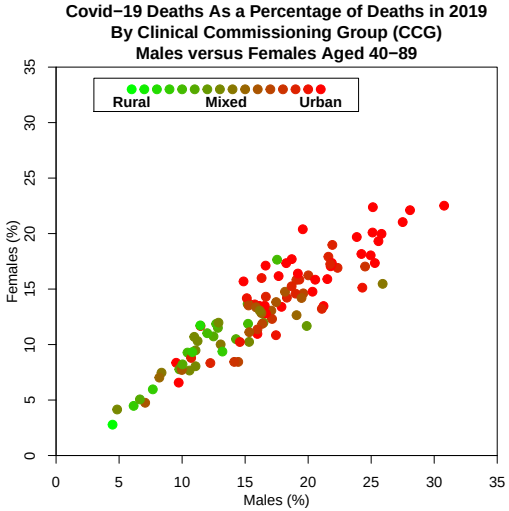
- Weekly or monthly data allow us to dig deeper and gain further insights
- 2020 $\rightarrow$ 2021 $\rightarrow$ 2022:
  - Vaccinations commence: older or clinically vulnerable first; healthy and younger later
  - Infection rates begin to vary much more by age, region, socio-economic group
  - New variants
- Plots reveal some of the impacts of these changes

Recap: Regional and sub-regional variation



- Considerable variation between regions
- London Covid death rates 170% higher than the South West

Covid Deaths in 2020 as a Percentage of All Deaths in 2019 By CCG



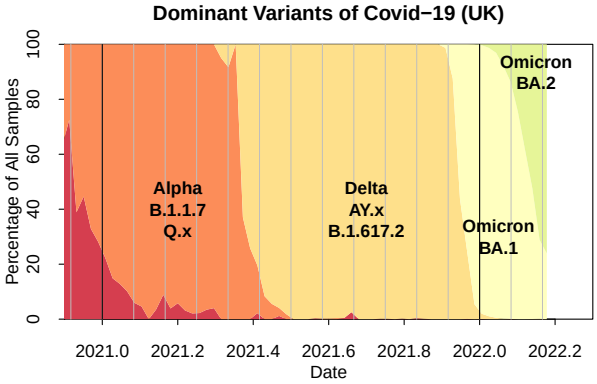
$D(\text{covid}, \text{CCG}, \text{sex}, 2020)/D(\text{all}, \text{CCG}, \text{sex}, 2019)$

- CCG: Clinical Commissioning Group = health administrative area average population $\sim 500,000$
- 106 CCGs across England
- Compare Covid-19 deaths in 2020 with deaths from all causes in 2019
- Covid-19 deaths: 5% to 30% of 2019 deaths
- Strong correlation between males and females
- Rural CCGs have much lower Covid death rates than urban

The impact of vaccination and new variants

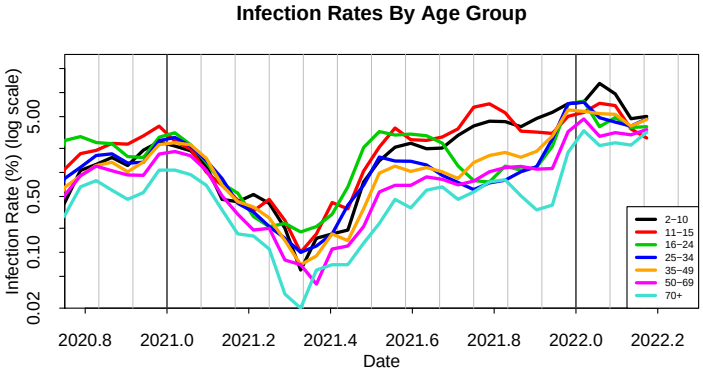
- Data for 2021: much more complex
- Vaccination: oldest ages in December 2020 $\rightarrow$ teenagers in October/November 2021
- New variants in the UK:
  - Alpha: December 2020
  - Delta: May/June 2021 (more infectious than Alpha)
  - Omicron BA.1: December 2021 (more infectious than Delta, less severe)
  - Omicron BA.2: February 2022 (more infectious than Omicron BA.1)
- What have been the impacts at different ages on:
  - Infection rates
  - Hospital admissions
  - Deaths

Dominant variants



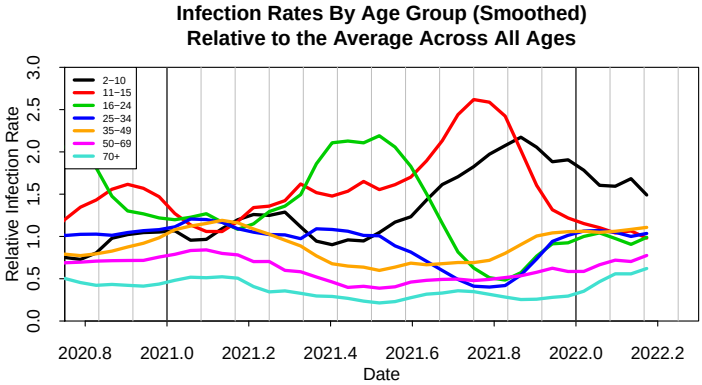
- Source: Office for National Statistics
- Each new variant takes over quite rapidly
- Does vaccination by age group have an impact?

ONS: Infection rates by age group (log scale)



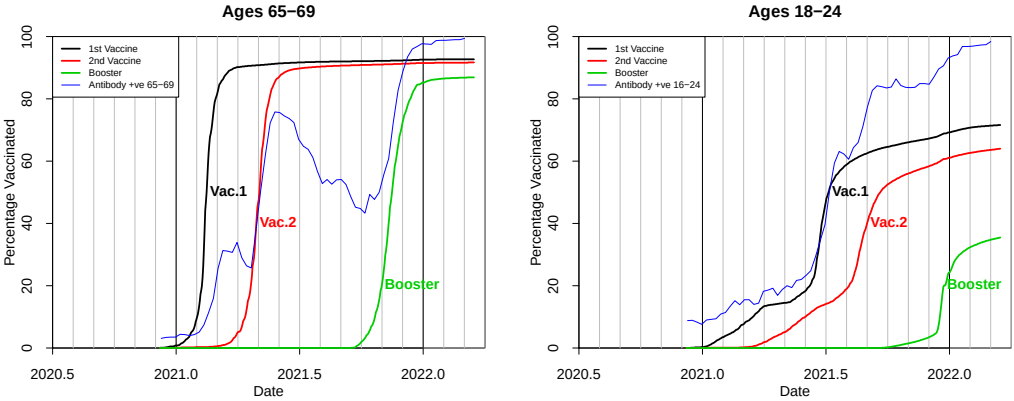
- Source: Office for National Statistics
- Note: "infection rate" measures Covid *prevalence* $\neq$ new cases (*incidence*)
- Clear waves of infections in different groups

ONS: Relative infection rates by age group



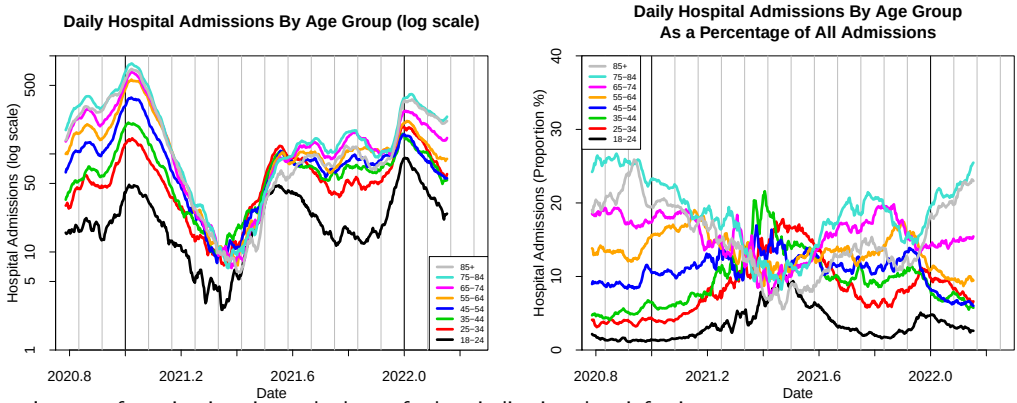
- $IR(t, \text{age group})/\bar{IR}(t)$ (with smoothing) $\Rightarrow$ remove effect of infection waves
- Highs and lows: different ages vaccinated at different times + different behaviour
- Ages 16-24 peak: vaccinations 1, 2 in June-Sept 2021; older groups months earlier
- Ages 11-15: later start to vaccination + end of summer holidays $\Rightarrow$ later peak

Vaccination and antibody status: Ages 65-69 and 18-24



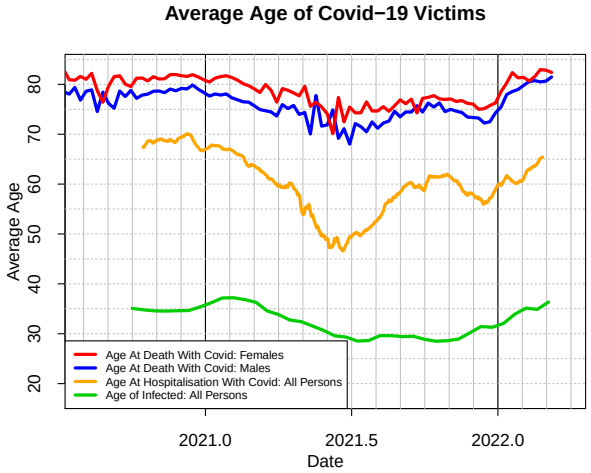
- Older groups: higher vaccine uptake; antibody decline
- Younger groups: clinically vulnerable vaccinated early + main wave of vaccinations
- All groups: by March 2022, almost 100% either infected or vaccinated; timing $\Rightarrow$ difficult to separate Omicron infections from impact of booster
- Some variation in vaccine uptake by region and socio-economic/ethnic group

Covid-related hospital admissions by age group



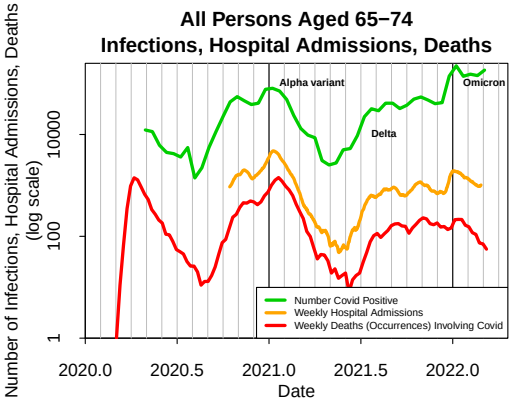
- Impact of vaccinations is much clearer for hospitalisation than infection rates
- Ages 75-84: early 2021 decline; later peak in 2021 (younger groups catch up + antibody decline); November 2021 booster
- Ages 25-34: mid-2021 peak prior to vaccinations
- March 2022: bunching up; ??? greater booster take-up amongst 45-64 versus 25-44

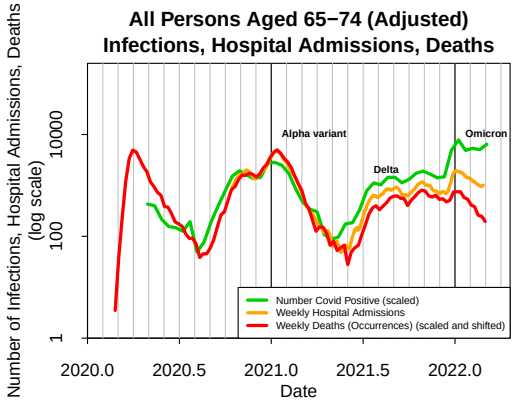
Average Age At Death With Covid and Average Age At Hospitalisation With Covid



- Pre-covid seasonal variation: around 1 year higher in winter
- End 2020 to mid 2021:
  - Avg Age at Death drops by 7 to 9 years
  - Avg Age at Hospitalisation drops by 20 years
- Due to:
  - vaccination by age group
  - age-related behaviour

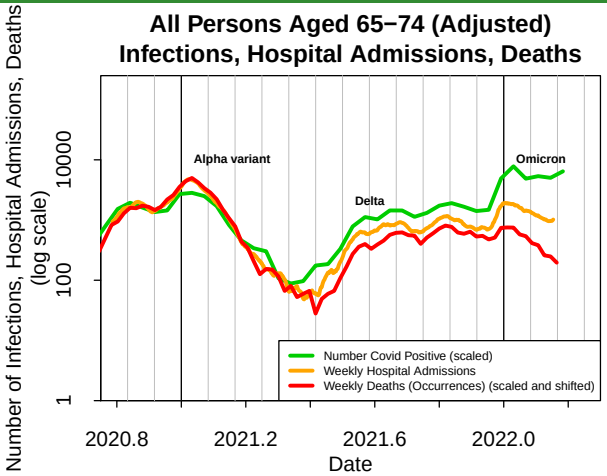
Compare infection rates, hospitalisations and deaths: Ages 65-74





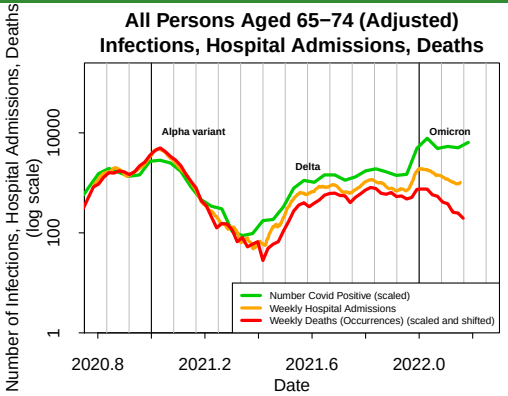
- Left: Infections >> Hospitalisations >> deaths; deaths lag by about 1 week or more
- Right: **shift** deaths; **scale** *infections down* and *deaths up* to match Nov/Dec 2020
- Clear alignment of peaks and troughs
- Improving survivorship through 2021, 2022

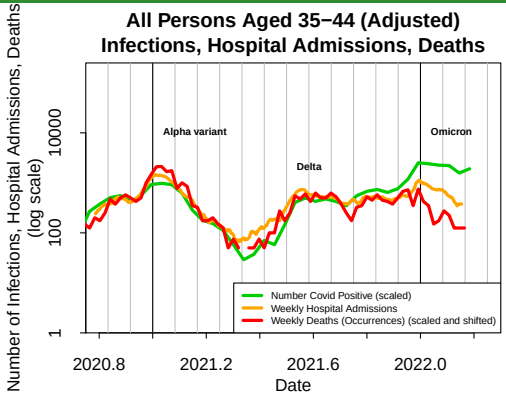
Vaccinations and relative improvements: Ages 65-74



- End 2020: Alpha variant more severe than predecessor
- February (??) and May 2021: Impact of vaccinations
- End 2021: Booster potentially widens gap
- Early 2022: Omicron BA.2 less severe than BA.1

Vaccinations and relative improvements: Ages 65-74 and 35-44



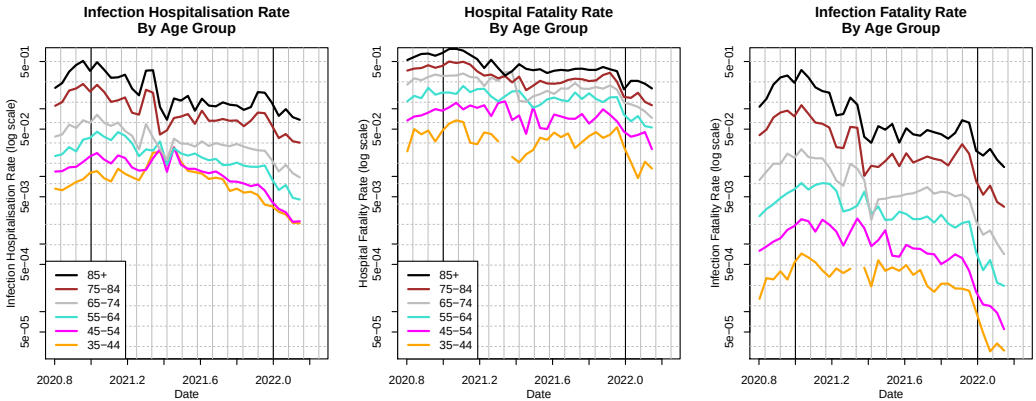


Compare February 2022 with December 2020 , ... given an individual has become infected:

- Ages 35-44: 78% less like to be hospitalised; 93% less likely to die
- Ages 65-74: 84% less like to be hospitalised; 97% less likely to die

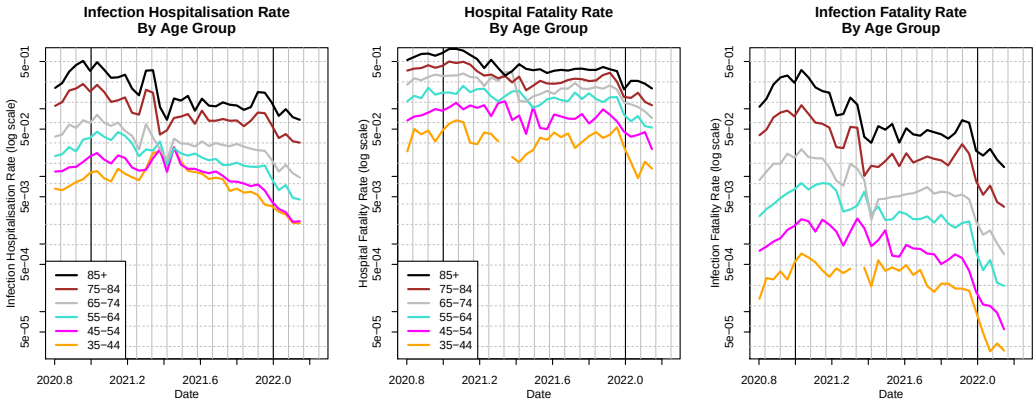
Reasons: severity of each variant; vaccination; duration of infected state

Estimated infection fatality rates and related quantities



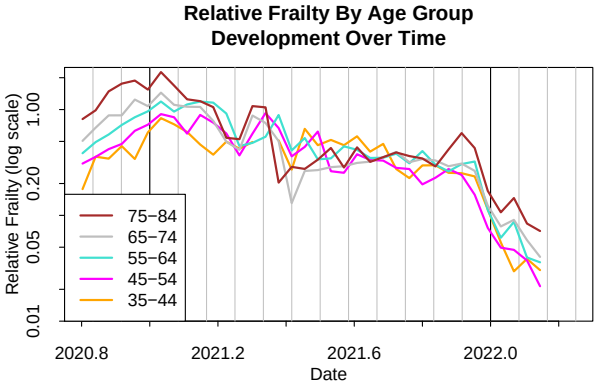
- Assumption: # new infections per day = infection prevalence÷10
- Infection Hospitalisation Rate = Proportion of newly infected who are admitted to hospital
- Hospital Fatality Rate = Proportion of newly hospitalised who die from Covid
- Infection Fatality Rate = Proportion of newly infected who die from Covid

Estimated infection fatality rates and related quantities



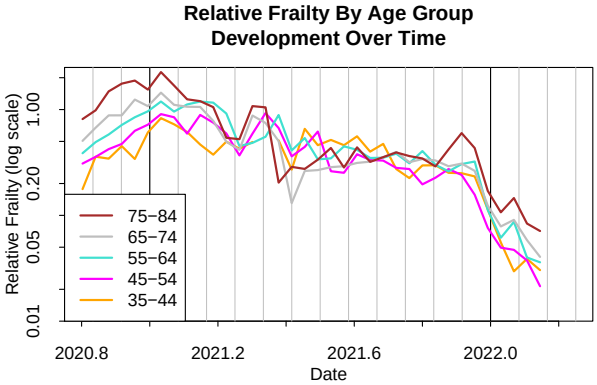
- Infection → Hospitalisation: strong benefit from vaccination
- Hospital → Dead: some vaccination effect, but weaker
- Infection Fatality Rate: declines sooner for the older groups due to vaccination
- Infection Fatality Rate: booster + Omicron ⇒ big decline

Estimated relatively frailty



- Relative Frailty (t, x) := Infection Fatality Rate (t, x) $\div$ All-Cause Death Rate $(2018, x)$
- All-cause Death Rate excludes external causes
- Steady decline as vaccines take effect and new variants replace older variants

Estimated relatively frailty: further remarks



- Pre-vaccination (end of 2020): relative frailty has some variation with age (increases by 3-4% per year of age)
- Vaccination causes the age gradient to disappear in mid 2021
- Age gradient re-emerges in 2022 after booster roll out to all age groups

Further analysis – Delta → Omicron + impact of vaccines

Nyberg, Ferguson et al. (Lancet, 2022): impact of variant, # vaccinations, age & vaccine (Astra-Zeneca/Pfizer/Moderna → Pfizer or Moderna booster)

- A more formal epidemiological study
- All of these factors have an impact on the relative risk
- If an individual has become infected
  - Omicron much less severe than Delta
  - Vaccines reduce severity
  - Booster had a significant impact in addition to Delta → Omicron switch
  - 1 or 2 Pfizer/Moderna vaccines were more effective than Astra-Zeneca
  - But Pfizer or Moderna booster eliminates the impact of first vaccine differences
- Takeaway: *relative frailty* quite stable during 2020
- 2021 onwards: *relative frailty* depends on vaccine + number of vaccines + timing + variant ⇒ very complex

Modelling future extreme events and mortality catastrophe bonds

- Many cat bonds use a mortality index linked to national mortality weighted by sex and age – often covering several countries
- Weights optimised to match hedger's exposures
- Index-linked $\Rightarrow$ bond principal at risk if the customised mortality index exceeds the attachment point (e.g. 120% of base mortality)
- Standard key assumption: national mortality variation is highly correlated with bond issuer portfolio mortality (amounts $\times$ lives)

Modelling future extreme events and mortality catastrophe bonds (cont.)

What has the Covid-19 pandemic revealed?

- Considerable variation by region/CCG and subgroups
- Some variation by age group beyond the proportionality hypothesis during 2021/22
- Impact of Covid-19 on an insurer depends on regional and other characteristics of their portfolio
- So, *in an extreme year*, the correlation might not be as high as anticipated
- Correlation will depend on how well diversified exposures are within each country
  - Regional
  - Urban/rural
  - Socio-economic
  - Age groups

Modelling future extreme events and mortality catastrophe bonds (cont.)

So: does the use and design of cat bonds need a rethink?

- Do they need to be based on national + sub-national indices?
- Hedge effectiveness calculations need to take account of sub-national variation and age-dependent variation in *relative risk*
- Will we see more indemnity-based bonds rather than index-linked?

Covid-19 versus other potential pandemics

Covid-19

- Waves 1 and 2: death rates approx. proportional to all-cause death rates
- Relative frailty(i, x) by group and age does not vary much in the pre-vaccine phase
  but does vary over time

Is this the result of

- the novelty of Covid-19 (i.e. no prior exposure to anything similar)?
- so underlying individual frailty determines outcomes.

Contrast with, e.g., 1918 Spanish Flu

- Relative frailty(i, x) was much higher for younger ages
- Reason: older age groups had prior exposure to other variants of influenza

Covid-19 versus other potential pandemics (cont.)

- A future Covid pandemic:
  some age groups potentially have higher levels of immunity to future new and dangerous variants
  (although 99% have now either been infected or have been vaccinated)

Generating future scenarios:

- Differentiate between novel viruses *versus* viruses with prior exposure
  meaning different levels of immunity/protection by age $\times$ region $\times$ subgroup
- Pandemic simulations need to allow for significant variation between
  - own life portfolio mix (diversification matters)
  - regions; urban/rural; socio-economic subgroups
  - age groups for viruses with prior exposure
  - age groups to allow for variation in social behaviour

Conclusions

- Proportionality hypothesis:
  - individual frailty is the main driver
  - infection rates by age and subgroup also important
  - stable relationship during 2020
  - vaccination and new variants $\Rightarrow$ much more complex in 2021 and 2022
- Mortality catastrophe bonds: do these need some redesign?
- Future extreme mortality scenarios:
  need to consider variation in extremes by region, age and socio-economic group

Thank you

E: A.J.G.Cairns@hw.ac.uk
W: www.macs.hw.ac.uk/∼andrewc

HERIOT WATT UNIVERSITY