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

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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

**Males: 75–84**

**Females: 75–84**

Source: HMD, STMF data series, accessed 4/10/2021

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

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Covid-19 Mortality
2020-22 in Context: English Weekly Mortality Rates Since 2014

Males: 75–84

Females: 75–84

Source: HMD, STMF data series, accessed 16/3/2022

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Covid-19 Mortality
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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
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).
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) \textit{relative to} the annual probability of death from all causes.
- The graphic suggests that \textit{infection rate}(x) \times \textit{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 $i$

Covid Mortality Rate($i, x$) = All-cause mortality rate($i, x$) $\times$ infection rate($i, x$) $\times$ 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

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

Infection rates: antibody prevalence data following the first wave ⇒
- 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)
Covid Mortality Rate\((i, x)\) = 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
**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 \(i = 1, \ldots, 10\)
Further plots and analysis

- Weekly or monthly data allow us to dig deeper and gain further insights

2020 → 2021 → 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 → 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?
Source: Office for National Statistics

Note: “infection rate” measures Covid prevalence ≠ new cases (incidence)

Clear waves of infections in different groups
ONS: Relative infection rates by age group

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<th>Date</th>
<th>Relative Infection Rate</th>
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<tr>
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<tr>
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<tr>
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<tr>
<td>2022.2</td>
<td>2.1</td>
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<table>
<thead>
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<th>Age Group</th>
<th>Relative Infection Rate</th>
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<td>2-10</td>
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<tr>
<td>11-15</td>
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<td>16-24</td>
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<td>35-49</td>
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</tr>
<tr>
<td>50-69</td>
<td></td>
</tr>
<tr>
<td>70+</td>
<td></td>
</tr>
</tbody>
</table>

\[ IR(t, \text{age group})/\bar{IR}(t) \text{ (with smoothing)} \Rightarrow \text{remove effect of infection waves} \]

- 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 ⇒ difficult to separate Omicron infections from impact of booster
- Some variation in vaccine uptake by region and socio-economic/ethnic 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

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Covid-19 Mortality
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 likely to be hospitalised; 93% less likely to die
- **Ages 65-74:** 84% less likely 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
- 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 \((t, x) := \text{Infection Fatality Rate} \left( t, x \right) \div \text{All-Cause Death Rate} \left( 2018, x \right)\)

- All-cause Death Rate excludes external causes
- Steady decline as vaccines take effect and new variants replace older variants
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
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 ⇒ 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 × lives).
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
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
- \( \text{Relative frailty}(i, x) \) 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
- \( \text{Relative frailty}(i, x) \) was much higher for younger ages
- Reason: older age groups had prior exposure to other variants of influenza
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 × region × 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 ⇒ 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

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