

Modelling and quantifying mortality and longevity risk

Module B3 : Projection during a pandemic

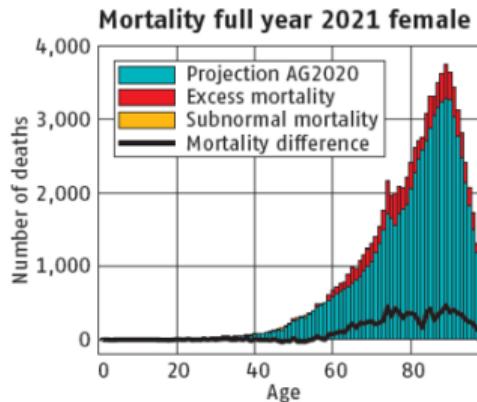
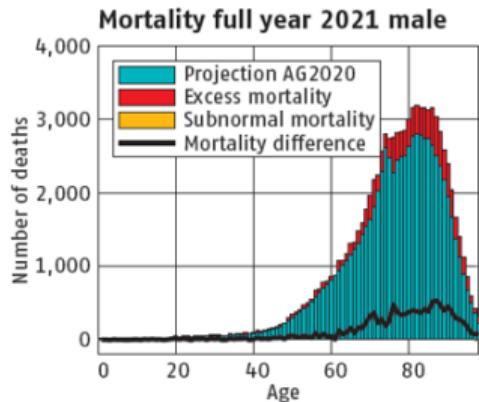
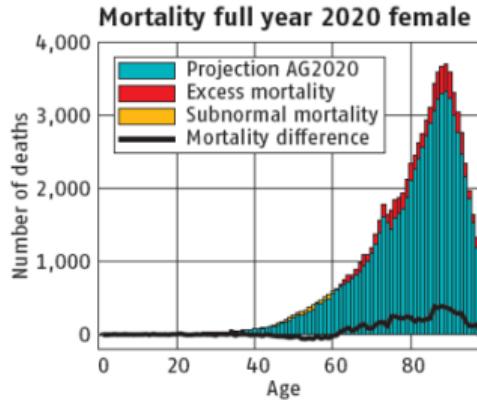
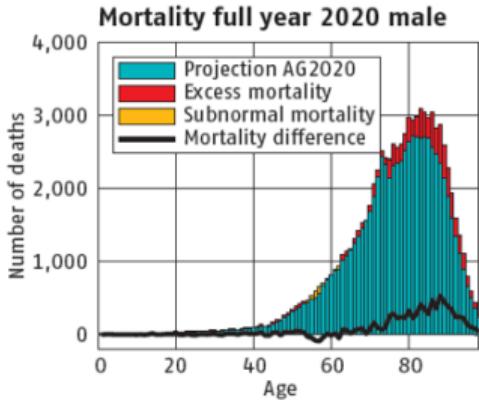
Michel Vellekoop

Actuarial Summer School
Warsaw, Sept 18-19, 2025

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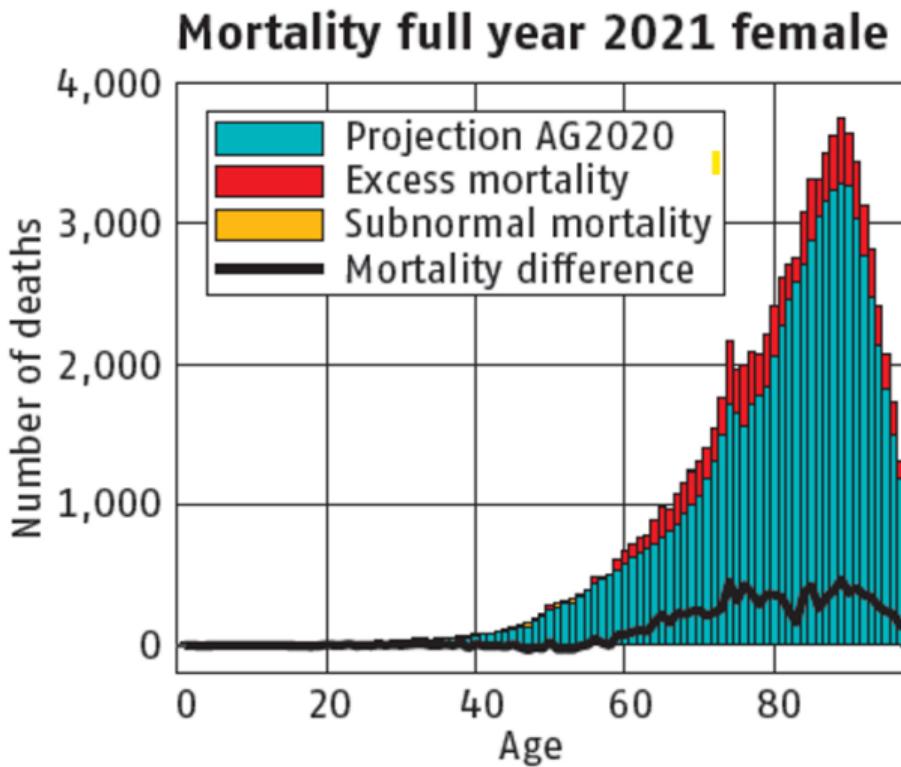
Projecting during a pandemic

COVID-19



- Modelling challenge:
Clear impact of (all !)
consequences of
COVID-19 in 2020 and
2021.
- Possible large impact
in future as well ?

COVID-19



- Modelling challenge:
Clear impact of (all !)
consequences of
COVID-19 in 2020 and
2021.
- Possible large impact
in future as well ?
- Impact per age differs
fundamentally from
pre- pandemic
dynamics!

Modelling Challenges

- Datasets 2020 and 2021 cannot be used for a ‘regular’ update.
- Model

$$D_{x,w,t}^g \sim \text{Poisson}(E_{x,w,t}^g \mu_{x,w,t}^g)$$

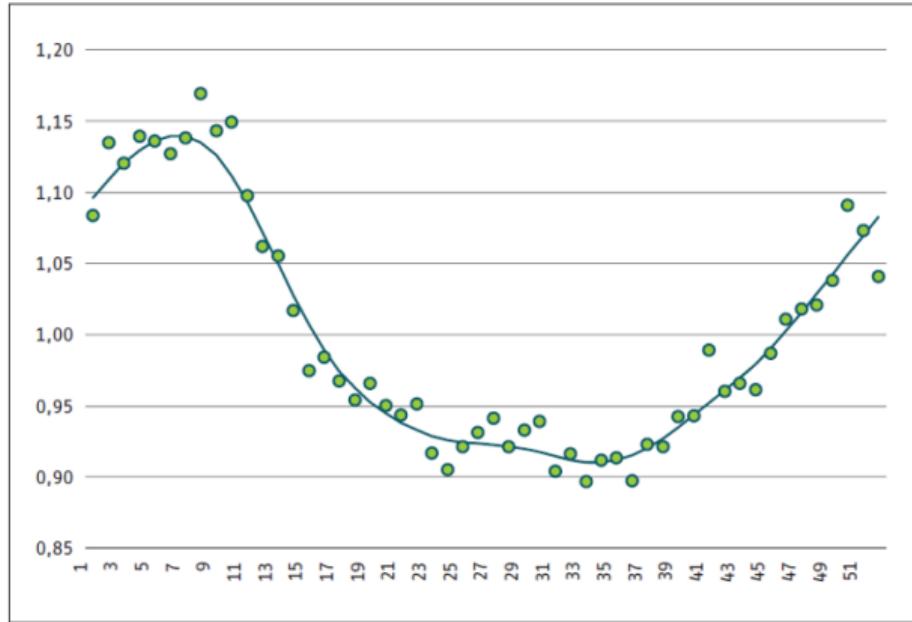
with $D_{x,w,t}^g$ extra data: deaths per week (and individual age)
 $E_{x,w,t}^g$ interpolation based on granular data

- New hazard rate

$$\mu_{x,w,t}^g = \mu_{x,w,t}^{g,\text{pre-COVID-NL}} \phi_{w,t} \exp(\mathcal{B}_x^g \mathcal{R}_{w,t}^g)$$

with $\mu_{x,w,t}^{g,\text{pre-COVID-NL}}$ Baseline: AG2020 model, updated by 2019 data
 $\phi_{w,t}$ seasonal effect
 \mathcal{B}_x^g COVID **age** effect
 $\mathcal{R}_{w,t}^g$ COVID **time** effect

Seasonal Effect



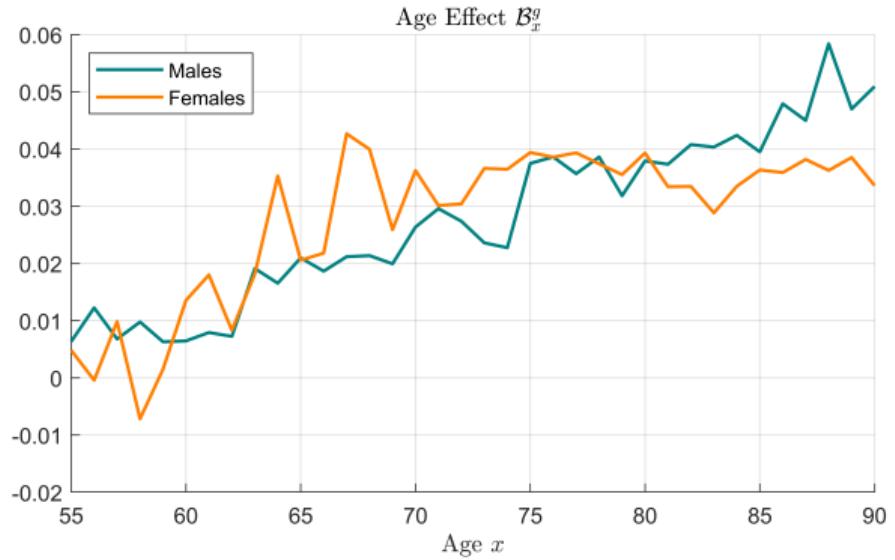
$$\mu_{x,w,t}^g = \mu_{x,w,t}^{g,\text{pre-COVID-NL}} \phi_{w,t} \exp(\mathcal{B}_x^g \mathcal{R}_{w,t}^g)$$

Relative mortality per week

- estimated using data from 2016-2019
- by fitting cyclical spline,
- assuming independence of gender.

Estimated Age Effect

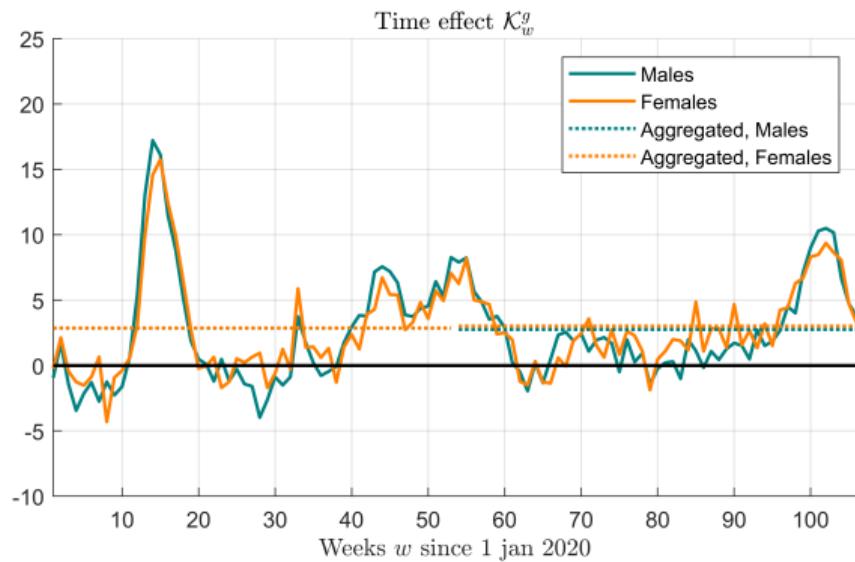
- Finer (weekly) data allows estimation of age effect based on more than just two data points.
- No effect before age 55, constant effect after age 90.
- Slightly different effect for males and females.



$$\mu_{x,w,t}^g = \mu_{x,w,t}^{g,\text{pre-COVID-NL}} \phi_{w,t} \exp(\mathfrak{B}_x^g \mathfrak{R}_{w,t}^g)$$

Estimated Time Effect

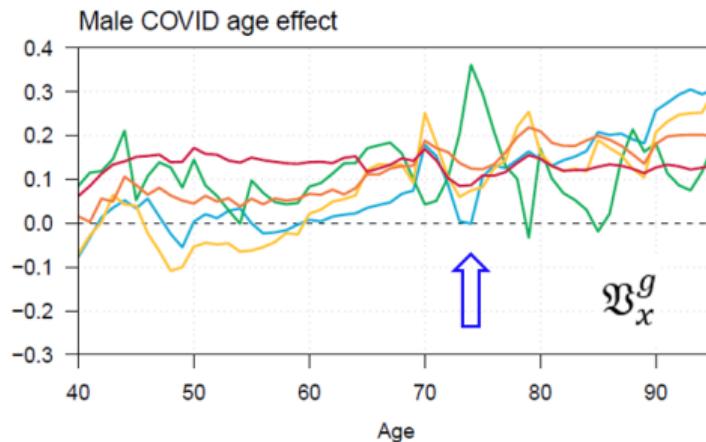
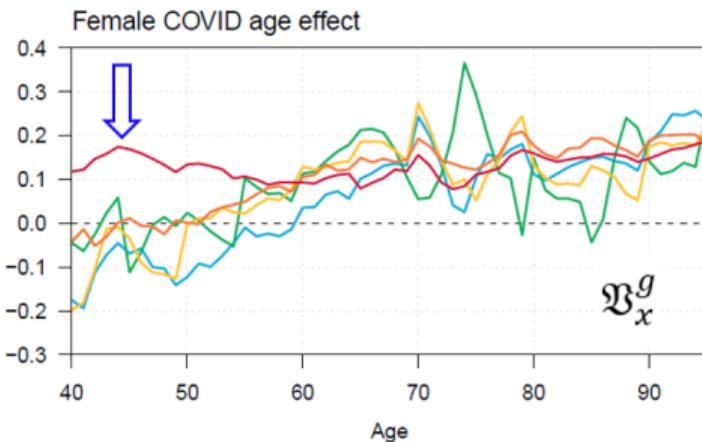
- Time series excess/reduced mortality (due to COVID or other factors) with respect to AG2020 model after 2019 data update.
- Dynamics represent impact of pandemic waves and mitigating measures.
- Aggregation of effects over weekly values $\kappa_{w,t}^g$ provides estimate for impact $\mathfrak{X}_{w,t}^g$ during entire year (dashed lines).



$$\mu_{x,w,t}^g = \mu_{x,w,t}^{g,\text{pre-COVID-NL}} \phi_{w,t} \exp(\mathfrak{B}_x^g \kappa_{w,t}^g)$$

Estimated Age Effect

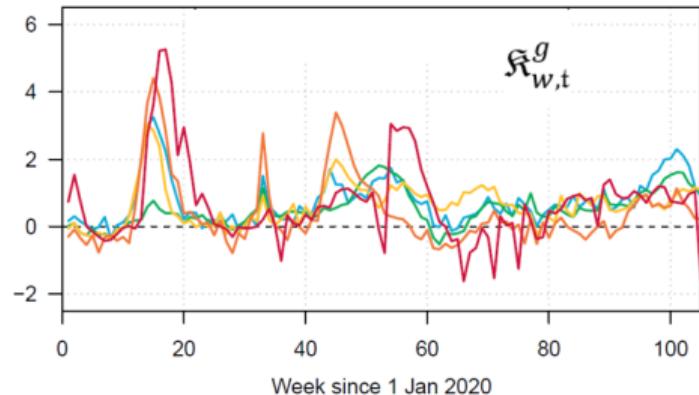
Research after publication AG2022: comparison different countries using data in STMF



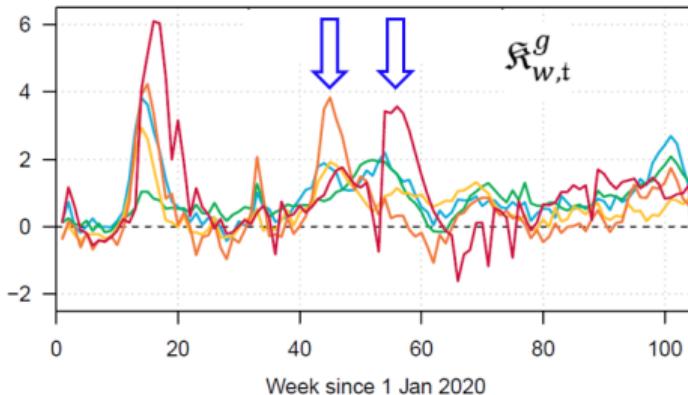
Estimated Time Effect

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Female COVID week effect



Male COVID week effect



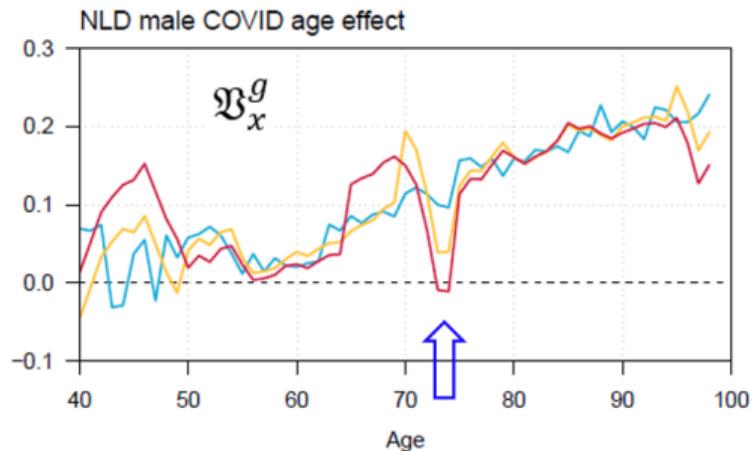
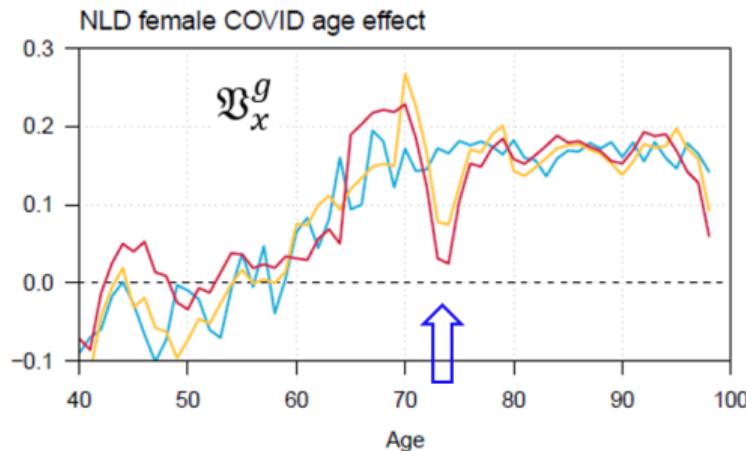
Week effects

Netherlands
UK
Belgium

Germany
France

Effect Granularity on Age Effect Estimates

Research after publication AG2022: comparison different countries using data in STMF

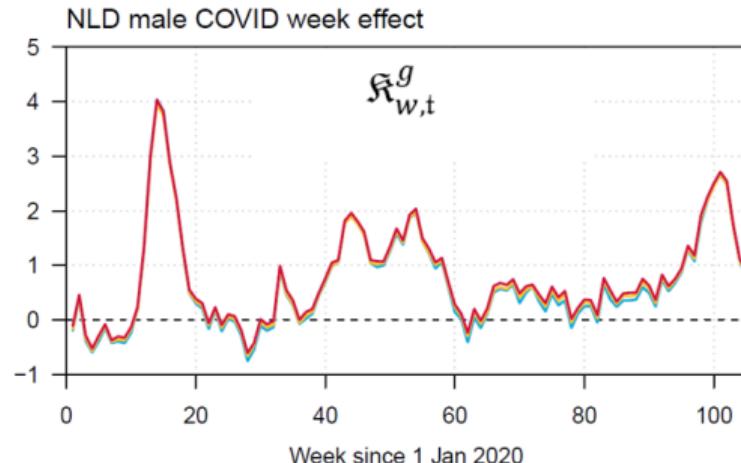
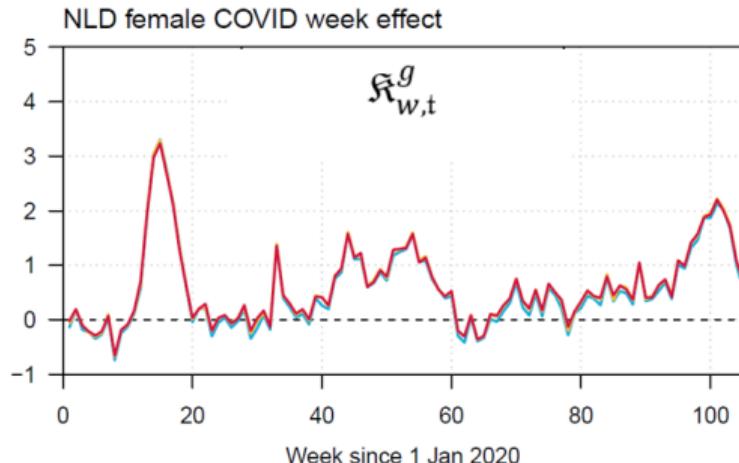


Dutch Age effects

estimate individual ages
estimate five-year age groups
estimate five groups (borders: 15/65/75/85)

Effect Granularity on Time Effect Estimates

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Dutch Week effects

estimate individual ages

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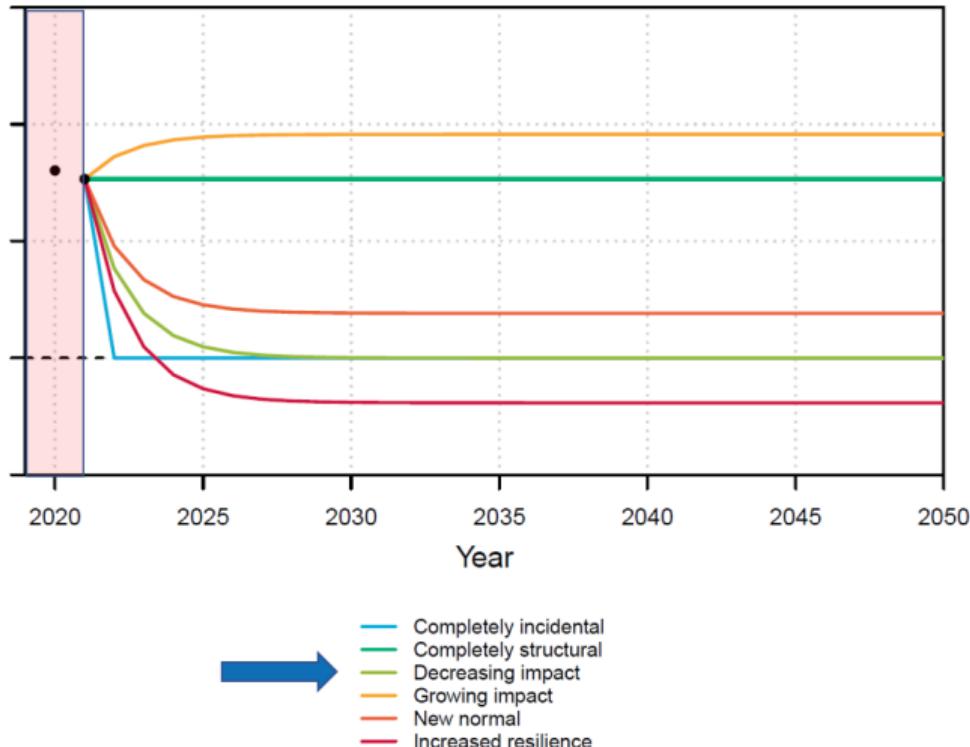
estimate five groups (borders: 15/65/75/85)

Estimated Time Effect

Future Scenarios for COVID time effect

- Estimated impact entire year in 2021 marks initial point for future scenarios.
- Additional assumptions are required to create prognoses future survival probabilities.
- AG2022: exponential decline chosen so small impact

(for short term)



Full model structure

$$\ln(\mu_{x,t}^g) = A_x^g + B_x^g K_t^g + \alpha_x^g + \beta_x^g \kappa_t^g + \tilde{\mathcal{B}}_x^g \mathfrak{x}_t^g$$

↓ ↓ ↓ ↓ ↓

↑ ↑ ↑

Fixed Age Effect Europe	Dynamic Age Effect Europe	Fixed Age Effect Deviation NL	Dynamic Age Effect Deviation NL	Dynamic Age Effect COVID in NL
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↑ ↑ ↑

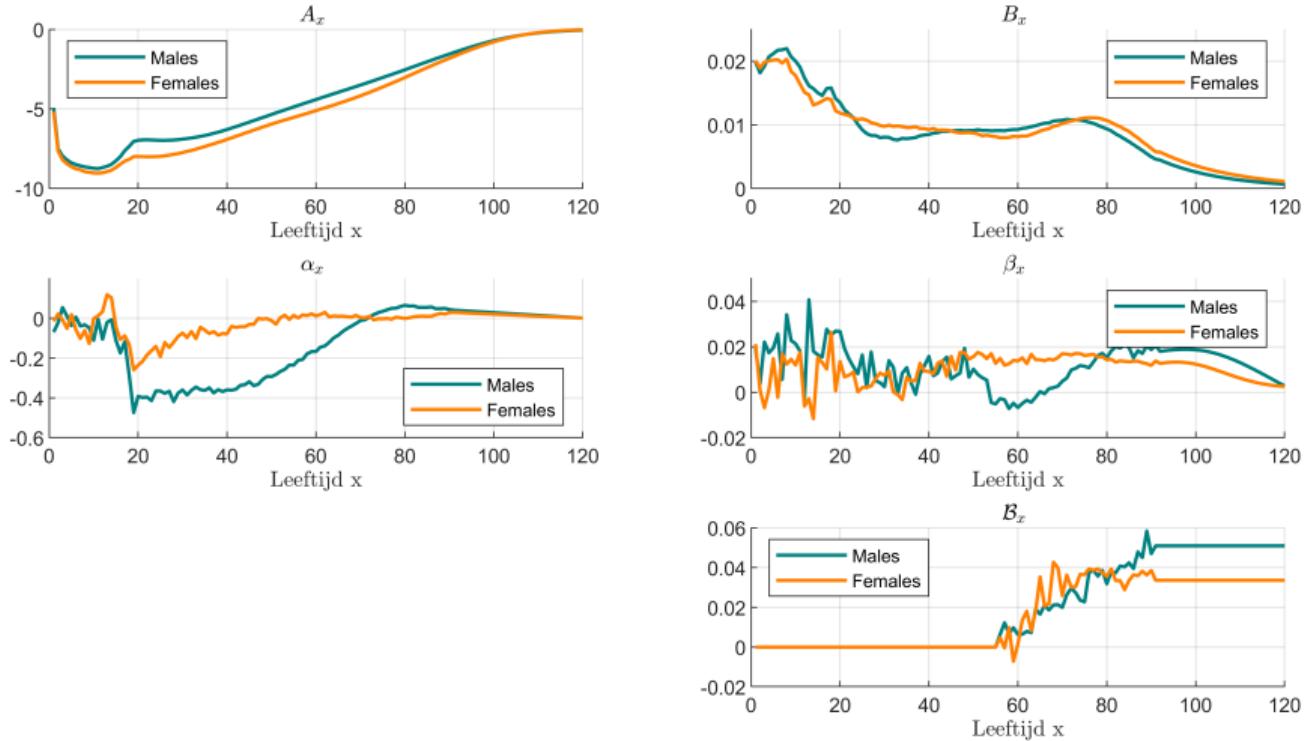
Time Effect Europe	Time Effect Deviation NL	Time Effect COVID in NL
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AG2020

AG2022

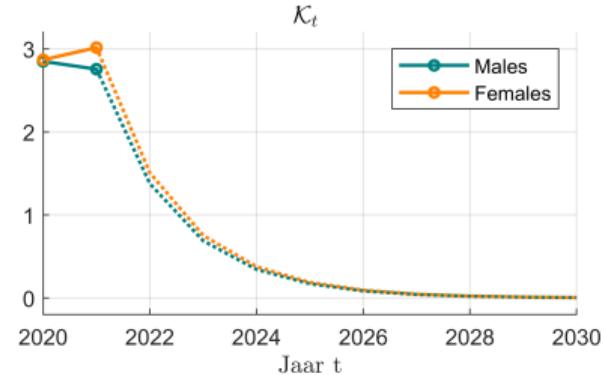
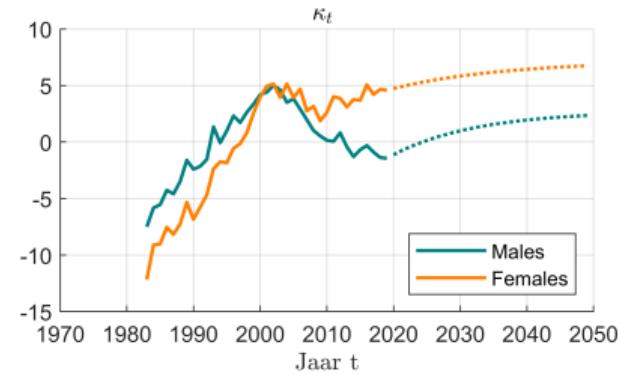
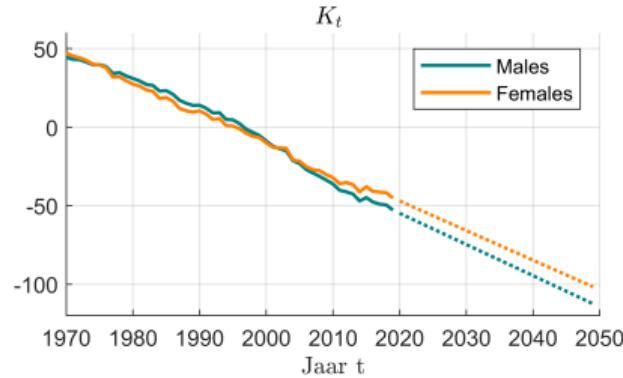
Full model structure: all age effects

Parameters AG2022: Age effects

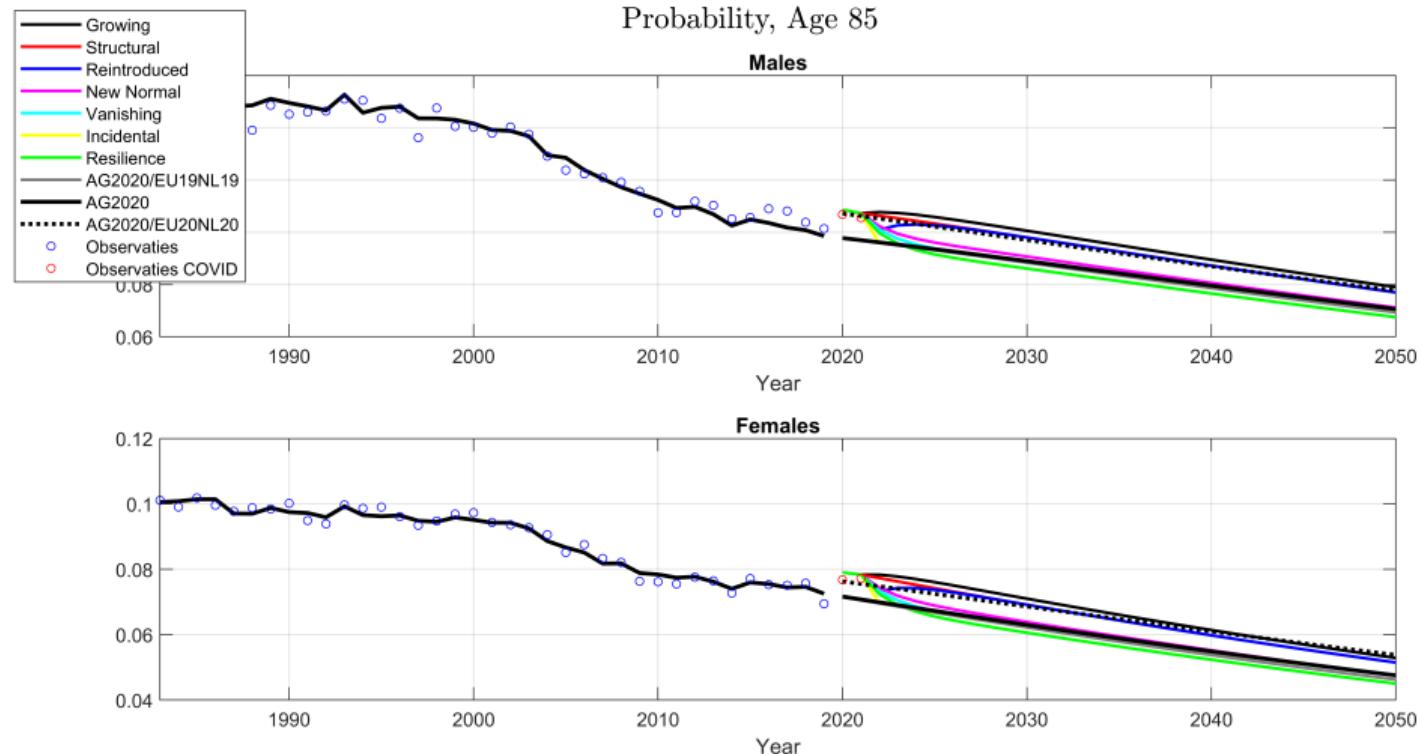


Full model structure: all time effects projected

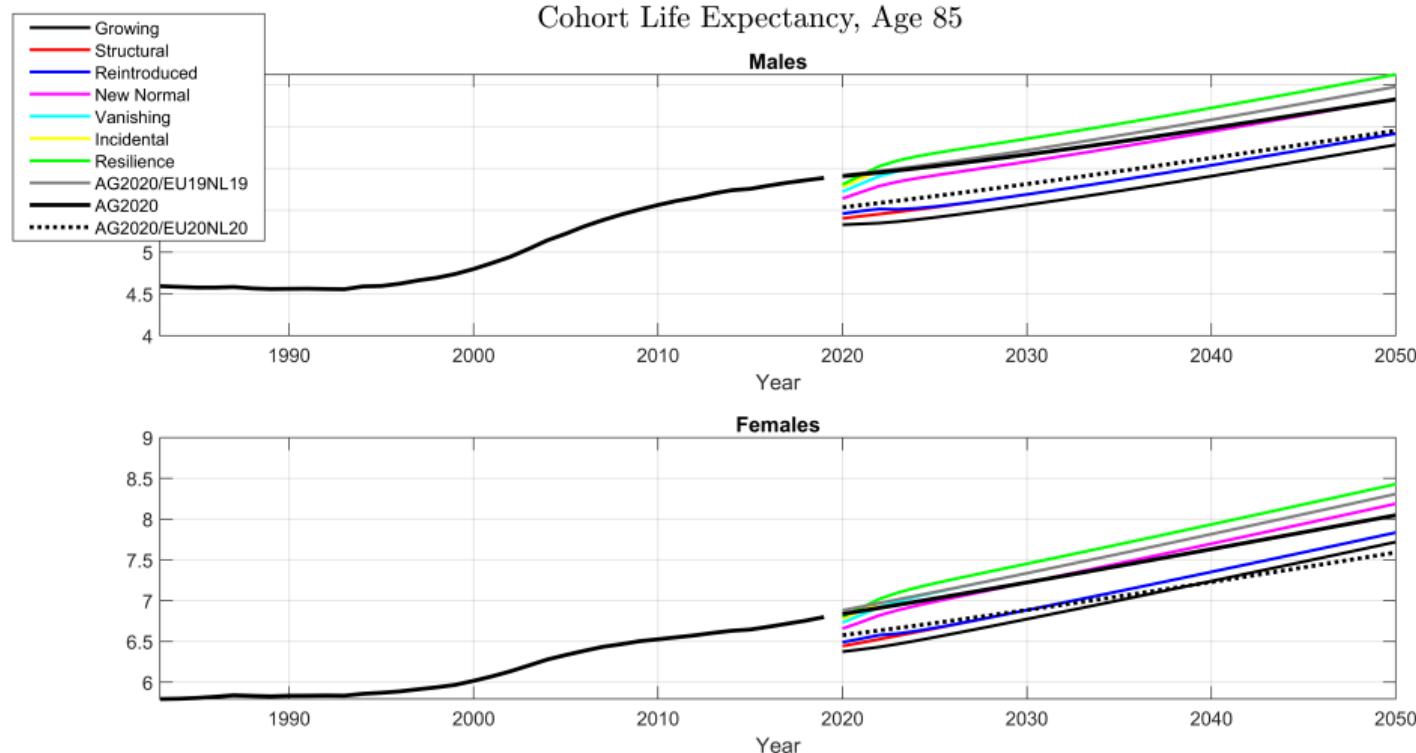
Parameters AG2022: Time series and projections



Alternative Scenarios: Probabilities ($x = 85$)

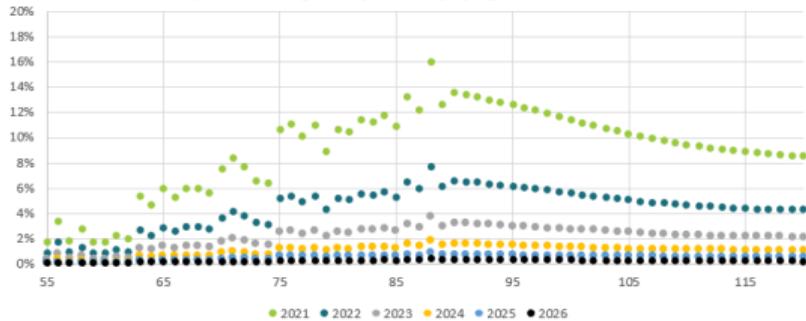


Alternative Scenarios: Cohort Life Expectancies ($x = 85$)

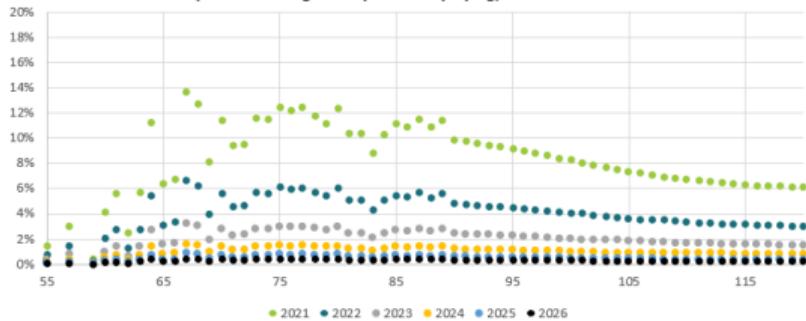


Impact

Impact: relative growth probability dying, males



Impact: relative growth probability dying, females



Impact on life expectancies very small, but

- Some impact **short term** survival probabilities
- **Filtering** COVID effects 2020/2021 for prognosis
- **Framework** for statistical modelling future impact, if needed ...

Impact

Cohort Life Expectancies in 2023

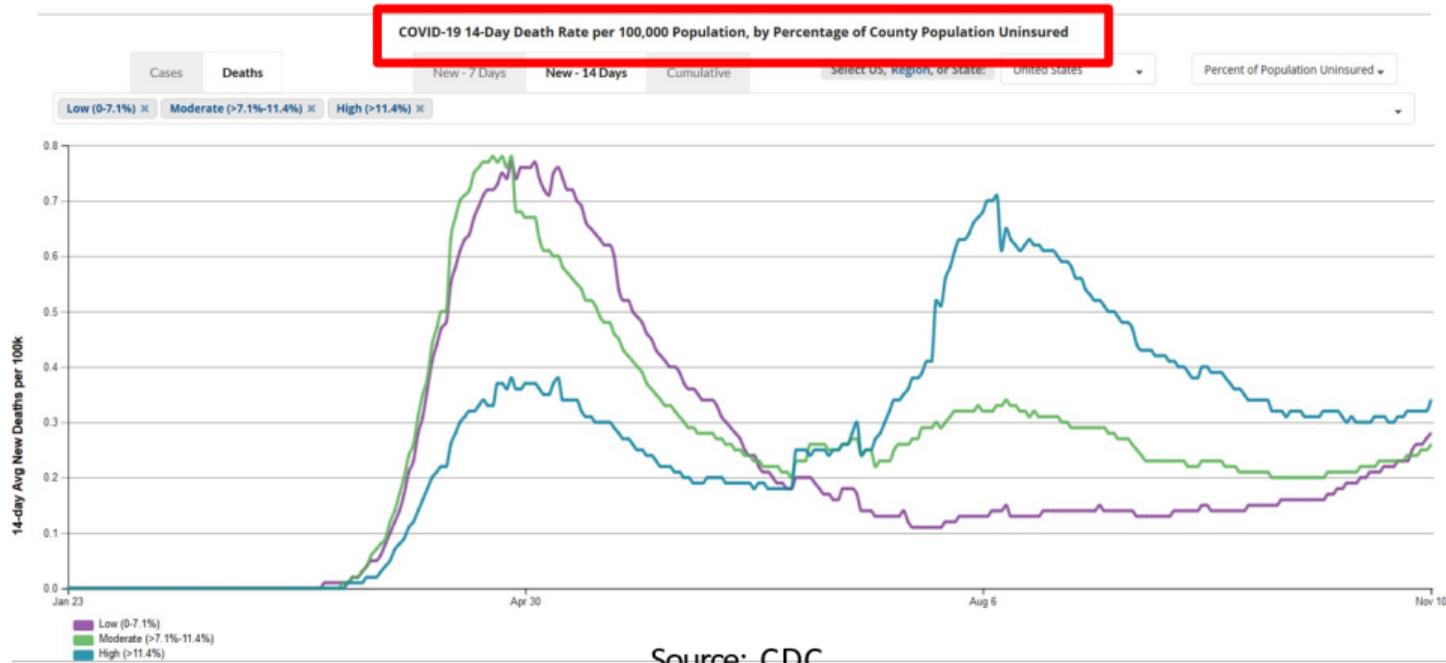
	At Birth		At age 65	
	Male	Female	Male	Female
AG2020	89.47	91.88	20.24	23.07
+EU2019	0.21	0.29	0.08	0.13
+Closure	0.36	0.59	0.04	0.08
+COVID-19	0.00	0.00	-0.01	-0.01
AG2022	90.04	92.76	20.35	23.27

Impact on life expectancies very small, but

- Some impact **short term** survival probabilities
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Insured population vs whole population

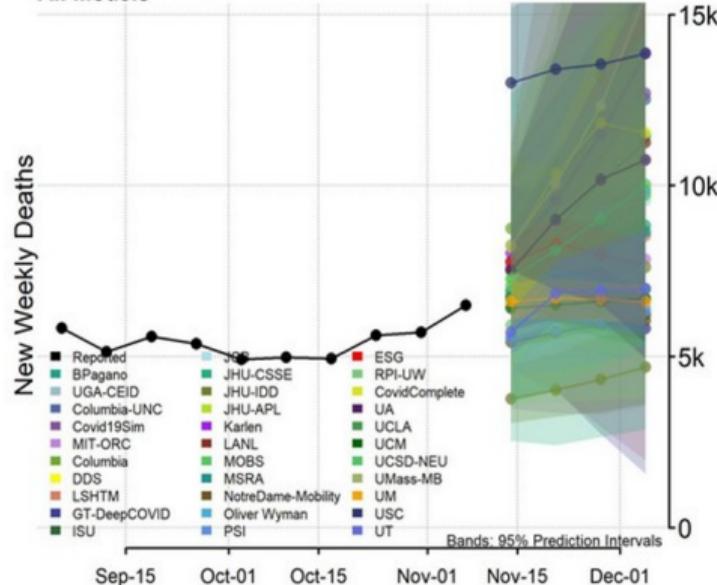
Trends in COVID-19 Cases and Deaths in the United States, by County-level Population Factors



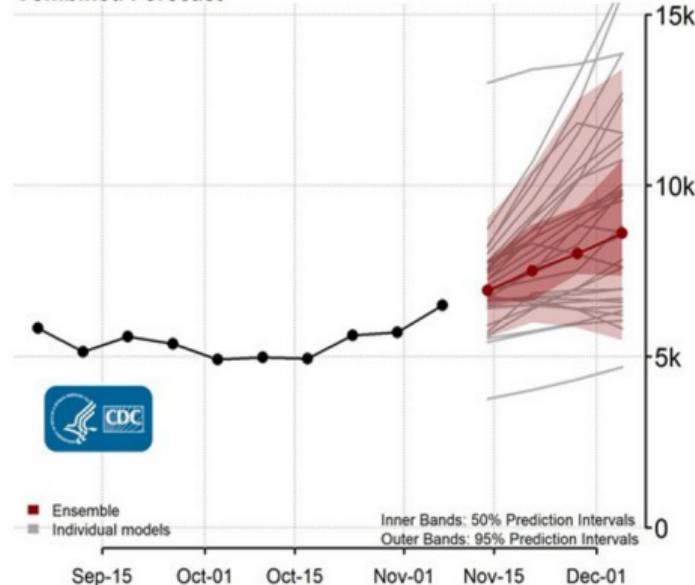
The Era of Overparameterization ...

National Forecast

All Models



Combined Forecast



More details about impact COVID-19



Insurance Mathematics and Economics 121 (2025) 144–156

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Insurance: Mathematics and Economics

journal homepage: www.elsevier.com/locate/ime



Estimating the impact of COVID-19 on mortality using granular data

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Key References

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- Brouhns, N., Denuit, M., and Vermunt, J.K. (2002) [A Poisson log-bilinear regression approach to the construction of projected lifetables](#). *Insurance: Mathematics and Economics* 31(3), 373-393.
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