

Modelling and quantifying mortality and longevity risk

Module B3 : Projection during a pandemic

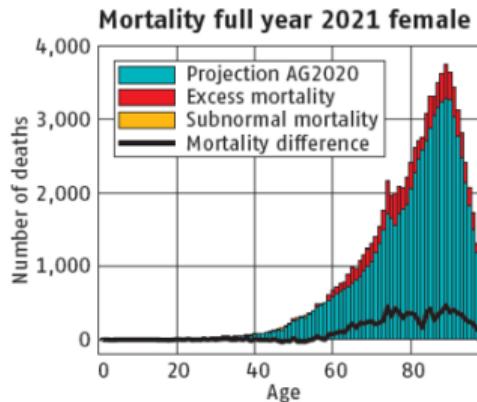
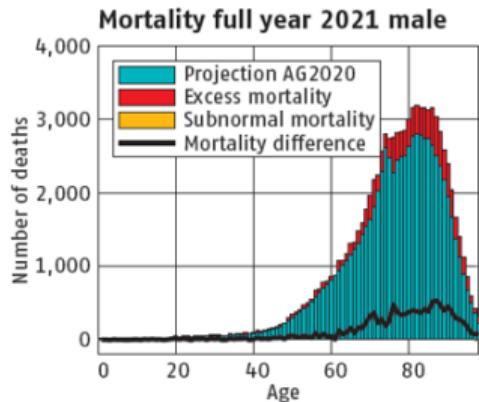
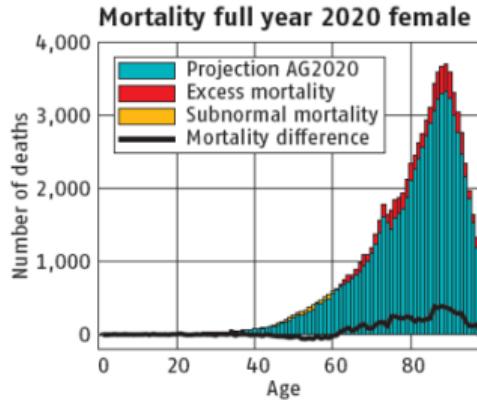
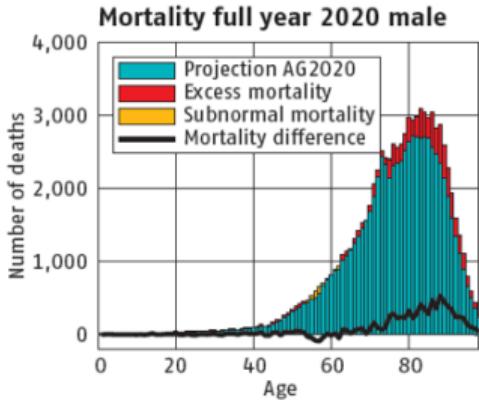
Michel Vellekoop

Actuarial Summer School
Warsaw, Sept 18-19, 2025

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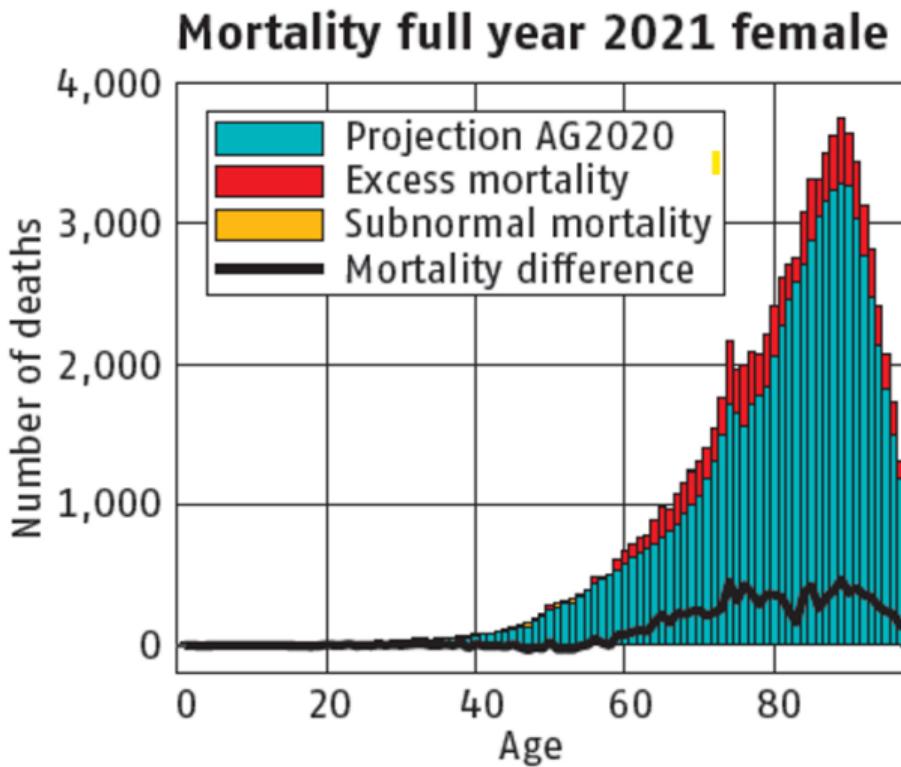
Projecting during a pandemic

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

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

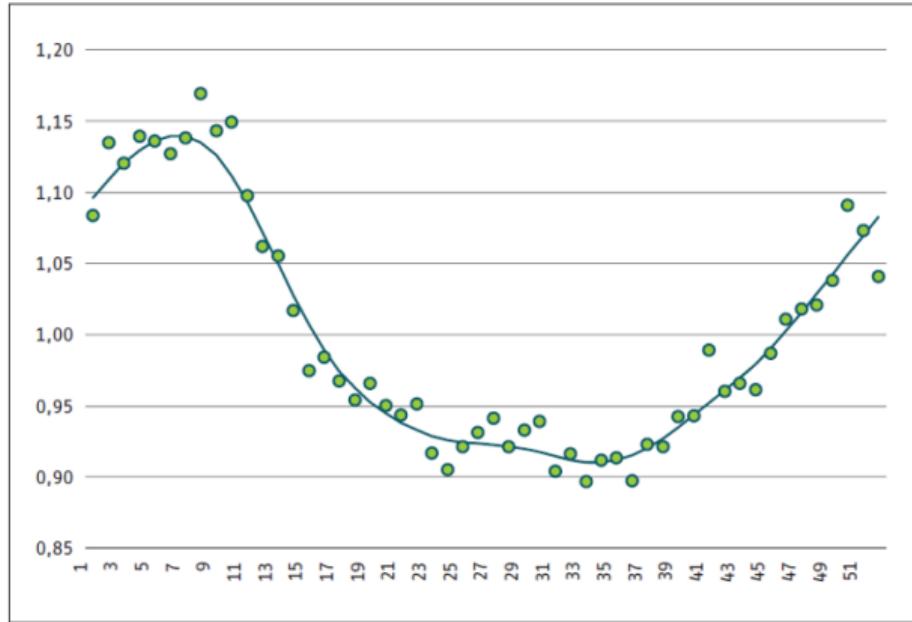
with $D_{x,w,t}^g$ extra data: deaths per week (and individual age)
 $E_{x,w,t}^g$ interpolation based on granular data

- New hazard rate

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

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



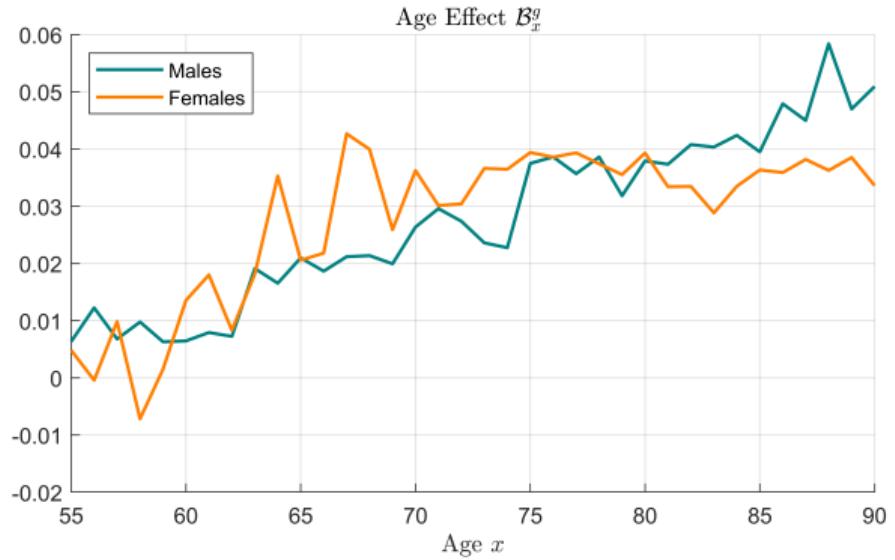
$$\mu_{x,w,t}^g = \mu_{x,t}^{g,\text{pre-COVID-NL}} \phi_{w,t} \exp(\mathcal{B}_x^g \mathcal{R}_{w,t}^g)$$

Relative mortality per week

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

Estimated Age Effect

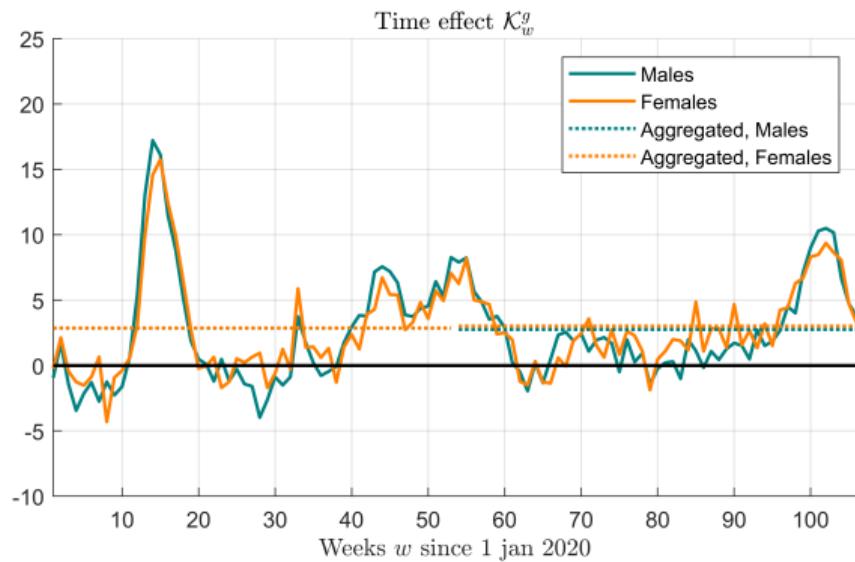
- Finer (weekly) data allows estimation of age effect based on more than just two data points.
- No effect before age 55, constant effect after age 90.
- Slightly different effect for males and females.



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

Estimated Time Effect

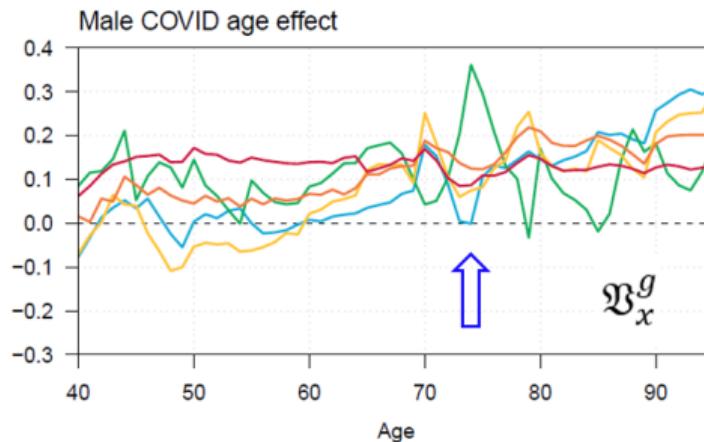
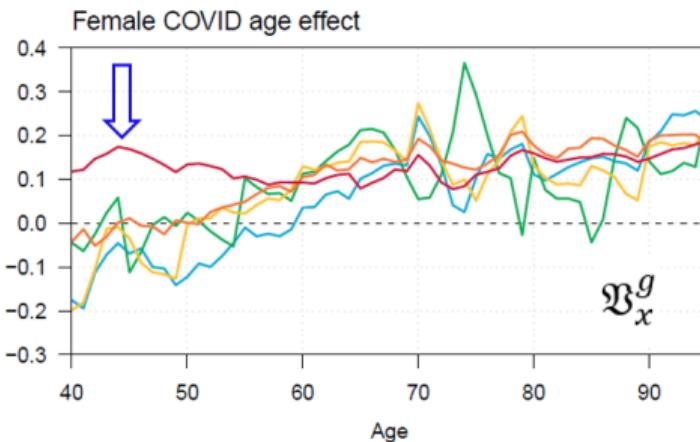
- Time series excess/reduced mortality (due to COVID or other factors) with respect to AG2020 model after 2019 data update.
- Dynamics represent impact of pandemic waves and mitigating measures.
- Aggregation of effects over weekly values $\mathcal{K}_{w,t}^g$ provides estimate for impact $\mathfrak{X}_{w,t}^g$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



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

Estimated Age Effect

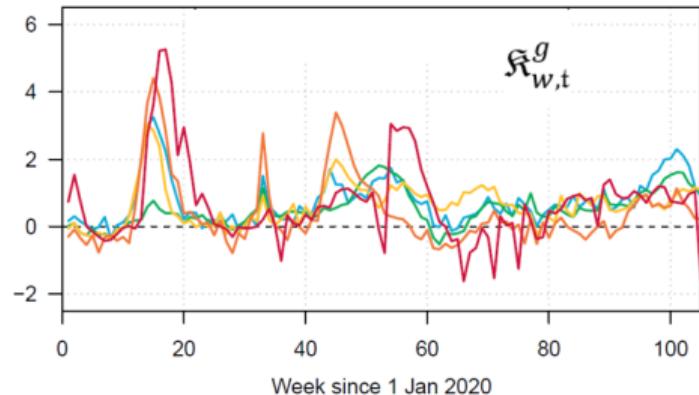
Research after publication AG2022: comparison different countries using data in STMF



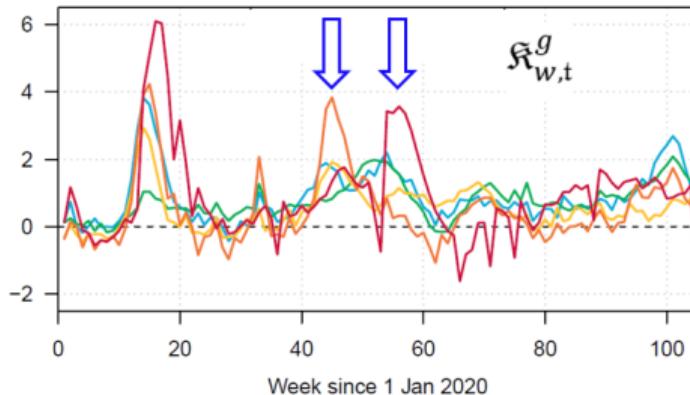
Estimated Time Effect

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

Female COVID week effect



Male COVID week effect



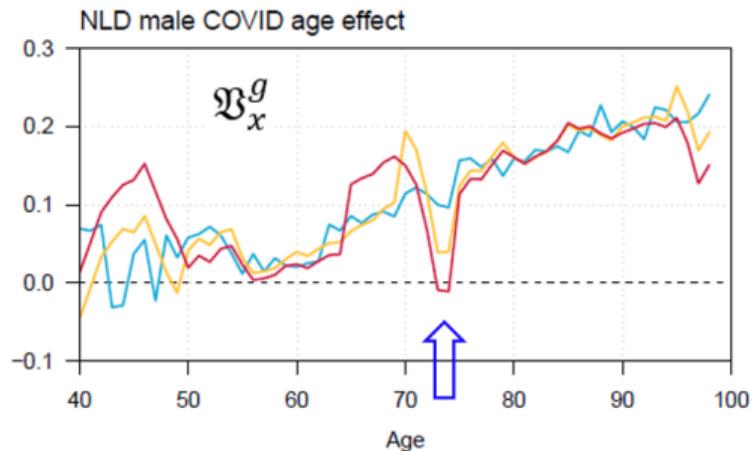
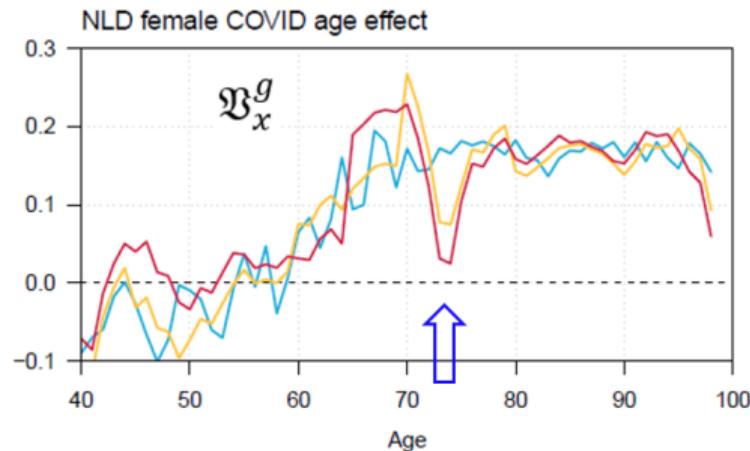
Week effects

Netherlands
UK
Belgium

Germany
France

Effect Granularity on Age Effect Estimates

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

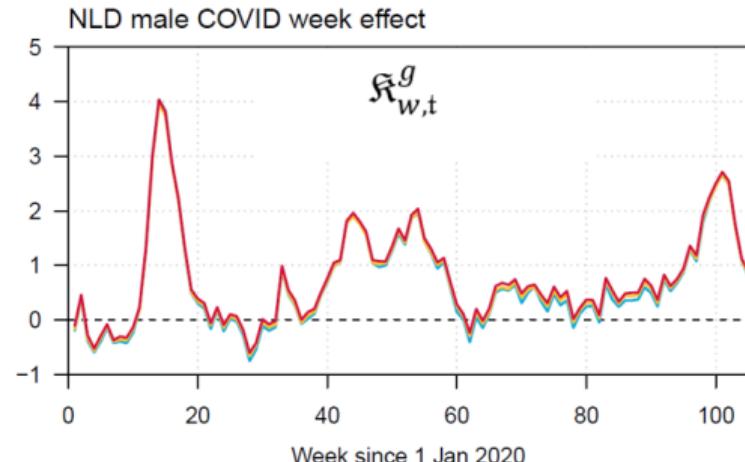
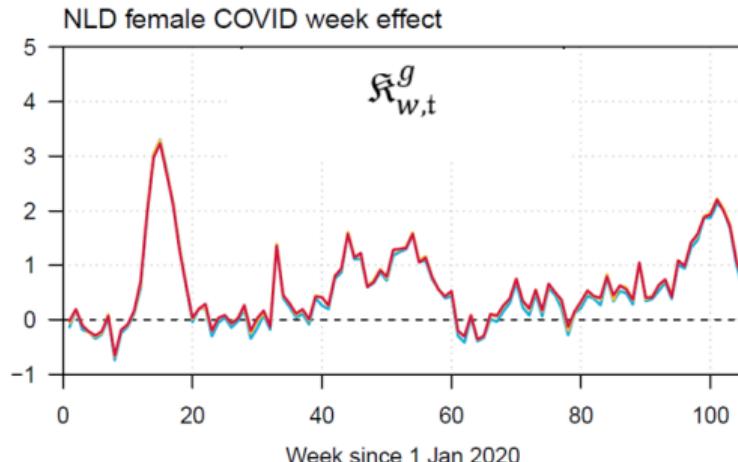


Dutch Age effects

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

Effect Granularity on Time Effect Estimates

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



Dutch Week effects

estimate individual ages

estimate five-year age groups

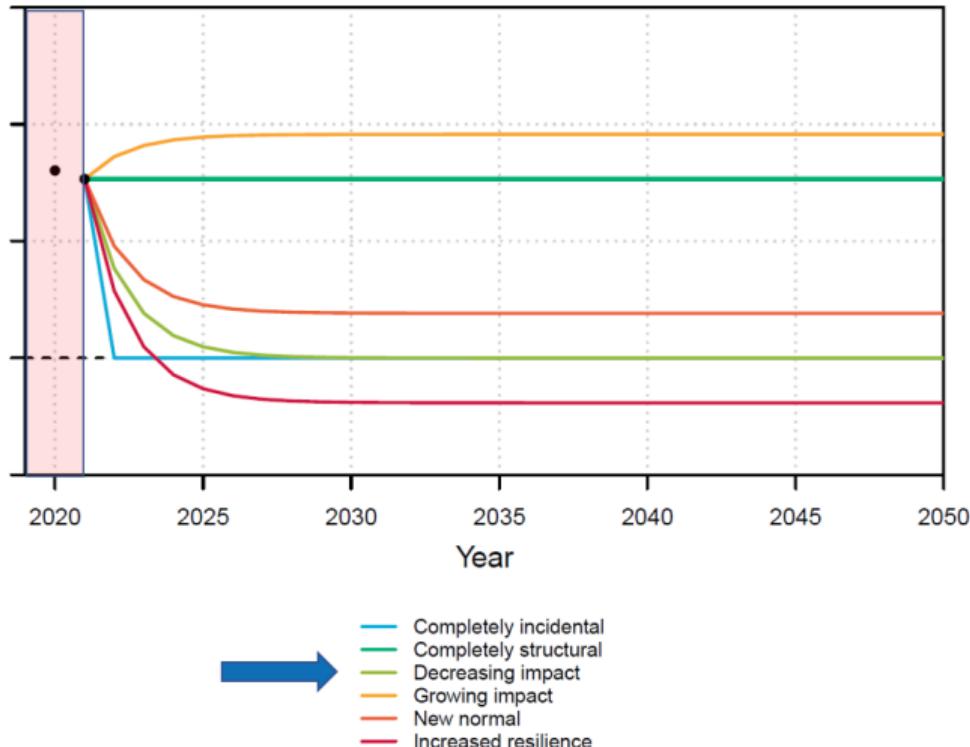
estimate five groups (borders: 15/65/75/85)

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

↑ ↑ ↑ ↑ ↑

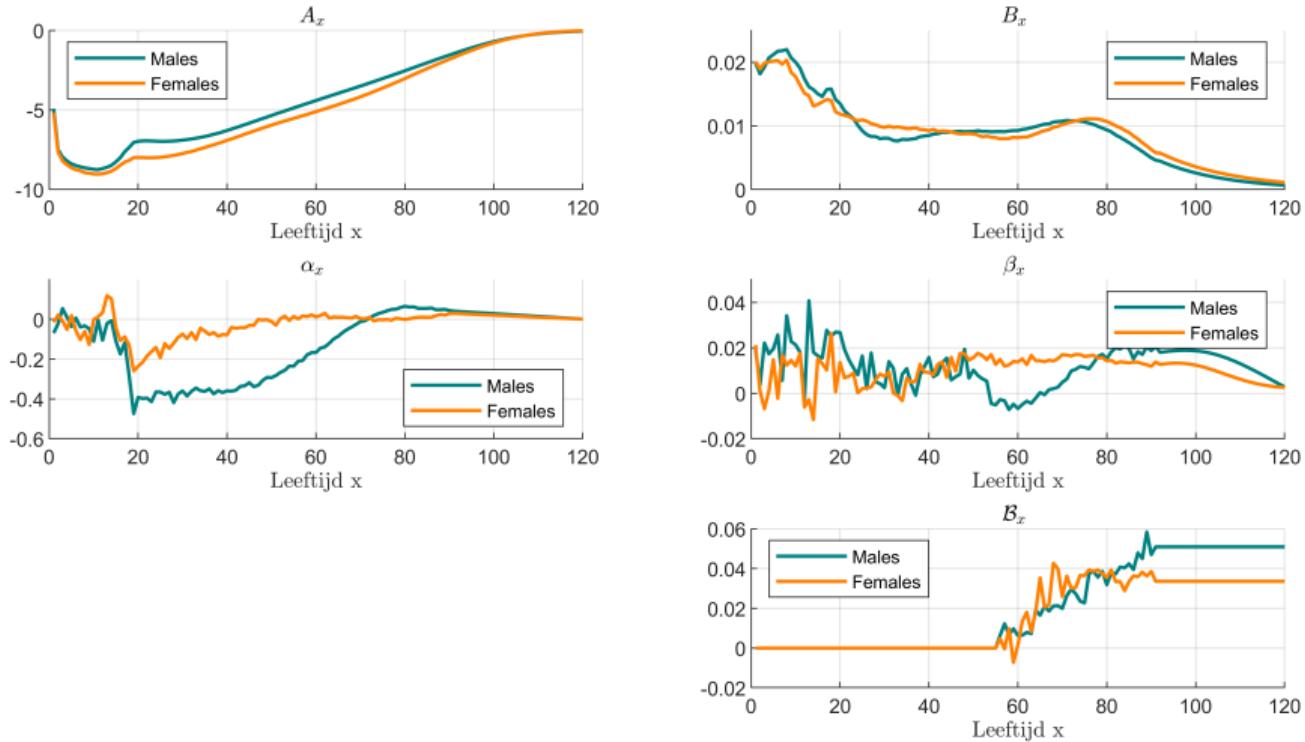
Time Effect Europe Time Effect Deviation NL Time Effect COVID in NL

AG2020

AG2022

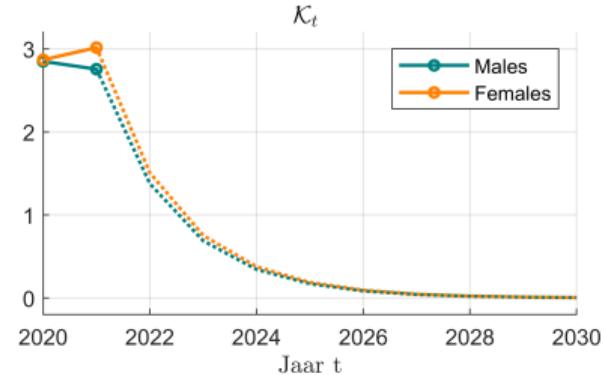
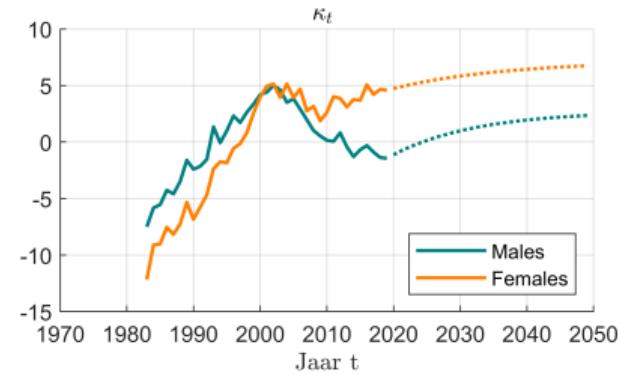
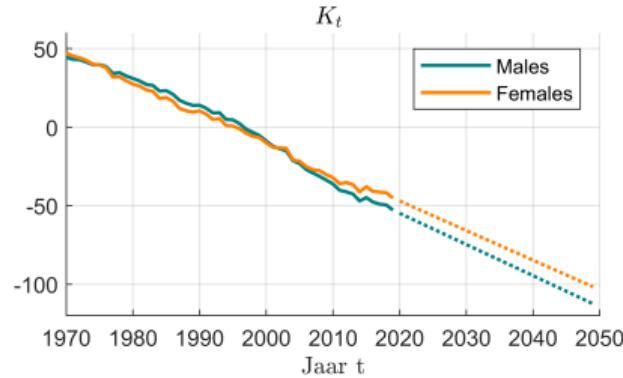
Full model structure: all age effects

Parameters AG2022: Age effects

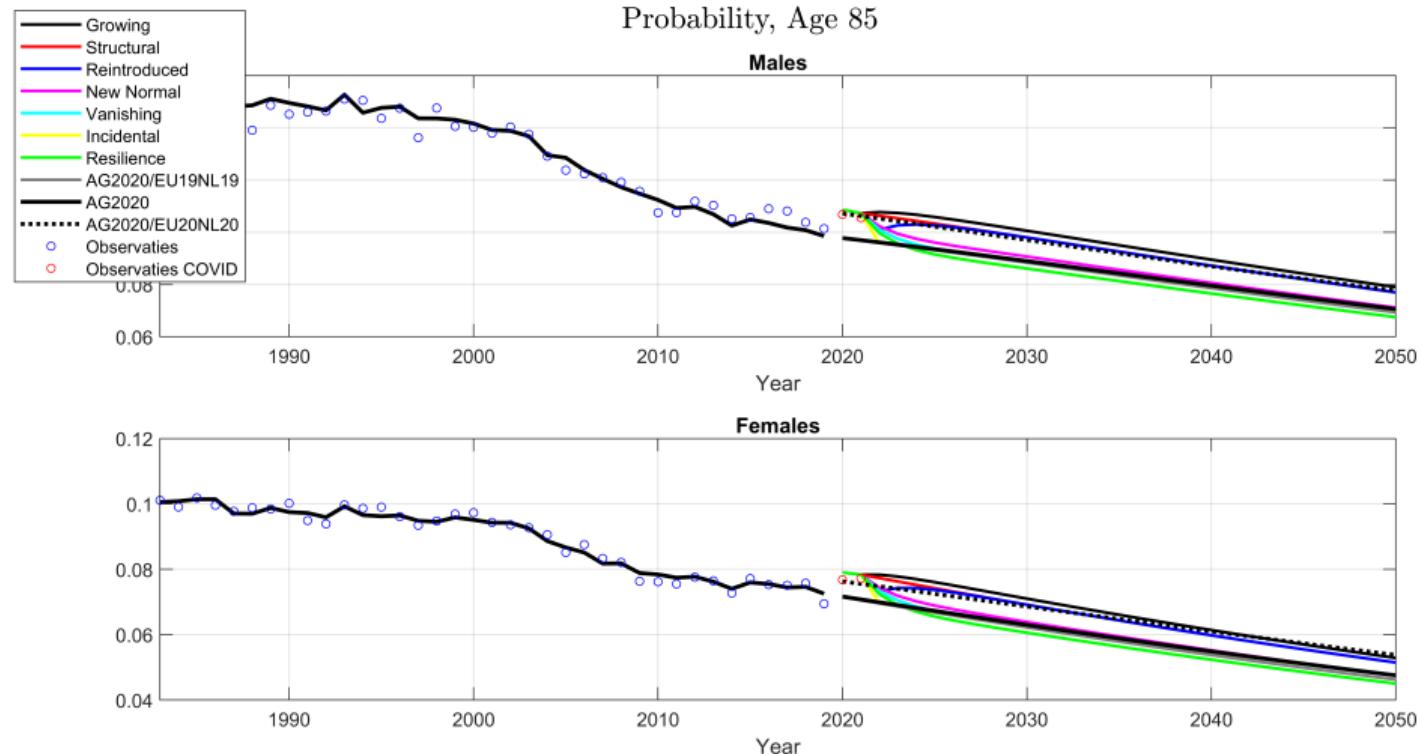


Full model structure: all time effects projected

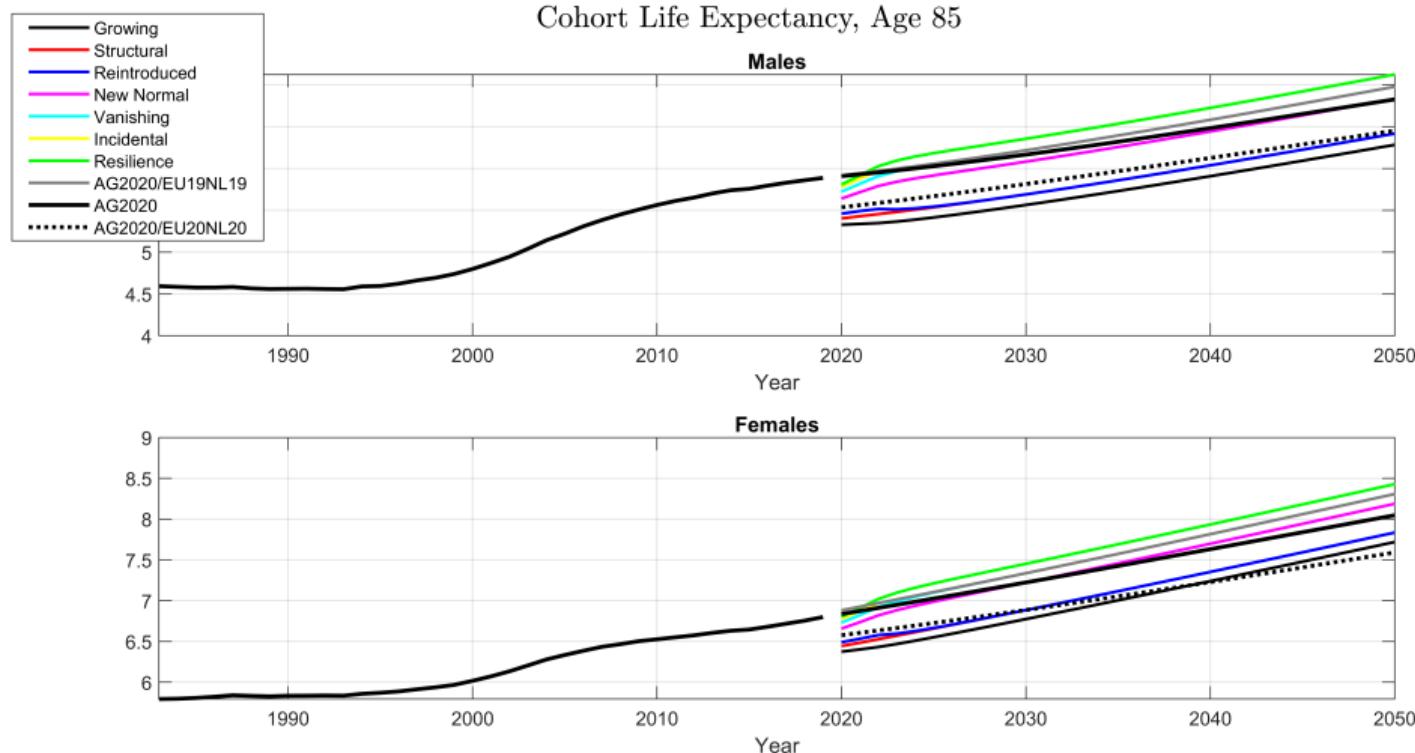
Parameters AG2022: Time series and projections



Alternative Scenarios: Probabilities ($x = 85$)

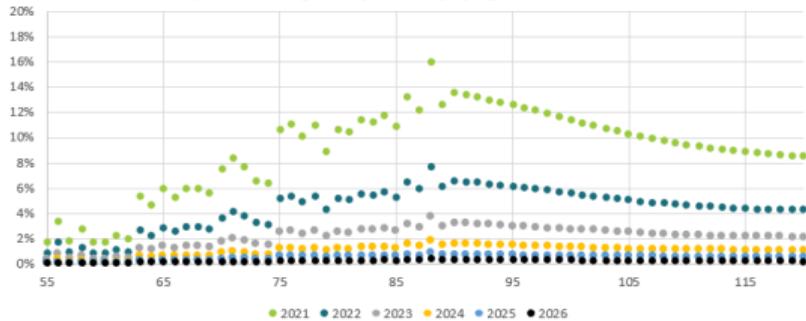


Alternative Scenarios: Cohort Life Expectancies ($x = 85$)

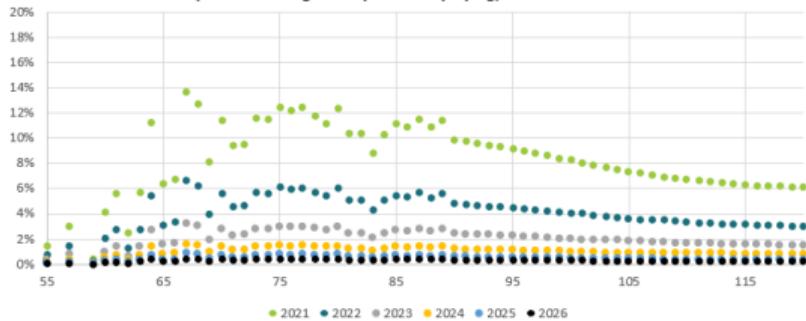


Impact

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

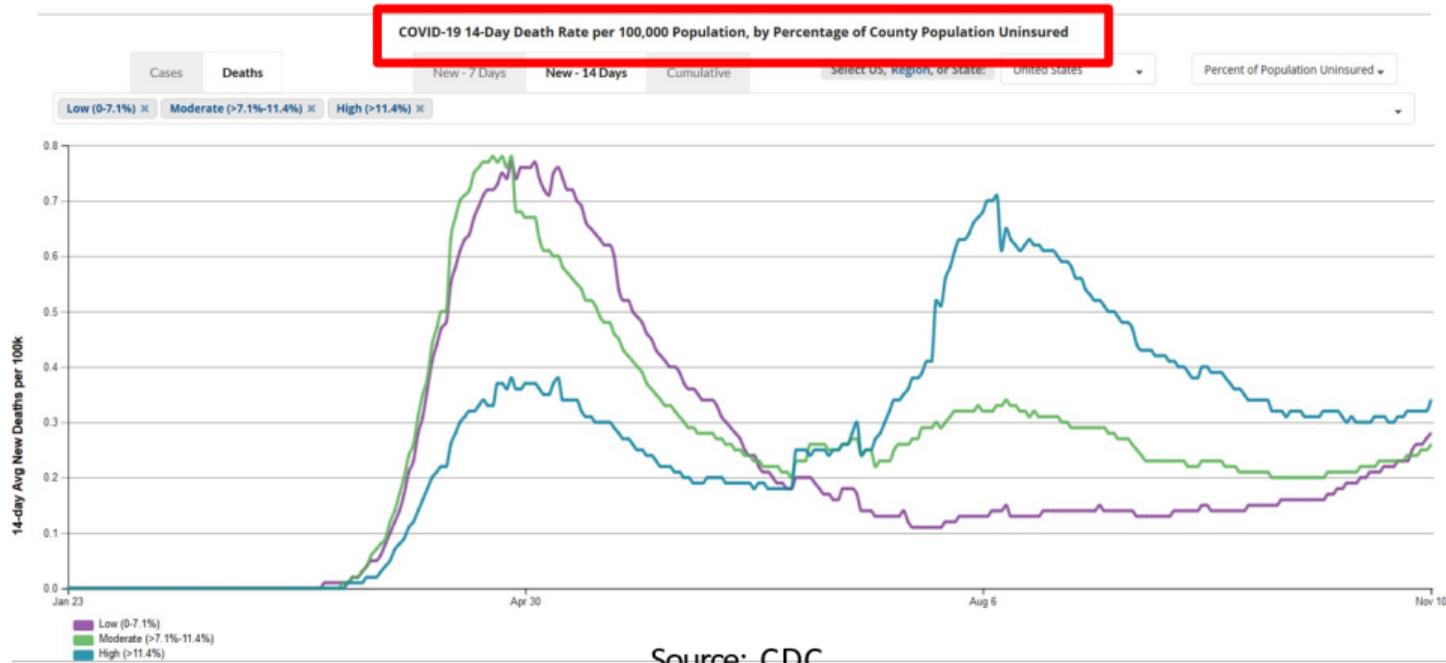
	At Birth		At age 65	
	Male	Female	Male	Female
AG2020	89.47	91.88	20.24	23.07
+EU2019	0.21	0.29	0.08	0.13
+Closure	0.36	0.59	0.04	0.08
+COVID-19	0.00	0.00	-0.01	-0.01
AG2022	90.04	92.76	20.35	23.27

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

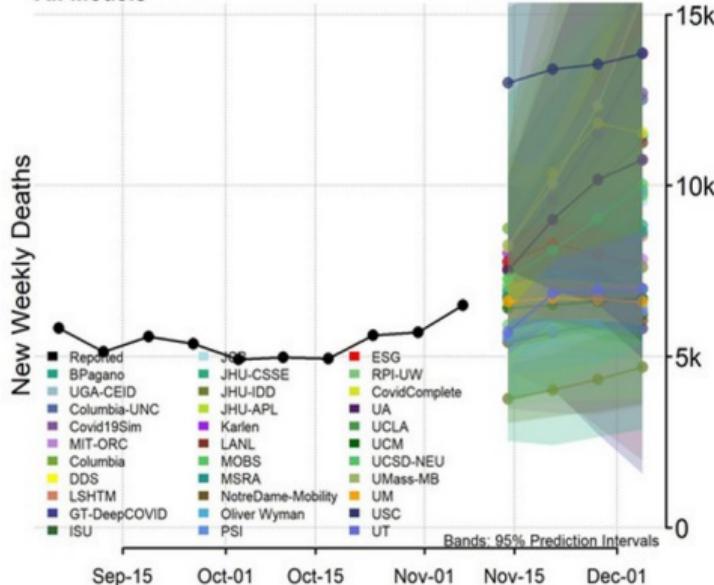


Source: CDC

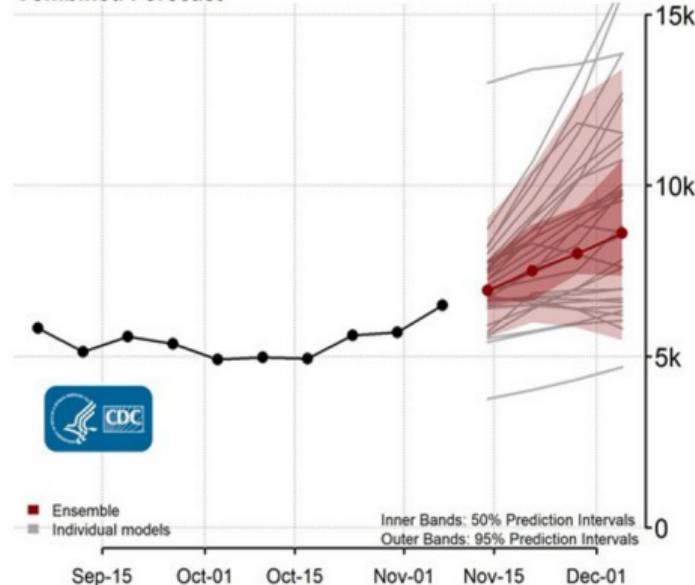
The Era of Overparameterization ...

National Forecast

All Models



Combined Forecast



More details about impact COVID-19



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

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Key References

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