Cause of death specific cohort effects in US mortality

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Outline

- Introduction
- Data availability
- A look at crude death rates
- Stochastic modelling
- Conclusions

Introduction

- Gain insight into the impact of socioeconomic status on mortality to inform projections.
- Analyse which causes of death affect different groups within a population.
- Try to understand the drivers of the observed behaviour through the analysis of cohort effects.

US mortality by single ages and calendar years, independently for each gender, CoD, and education level.

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Education as a covariate in death rates

- Education $\Rightarrow$ Socioeconomic status.
- "Fixed" through adulthood.
- Data readily available (quality to be assesed though!).

Case and Deaton (2015) found interesting trends in cause of death mortality in the US by education level.

Data availability

Data combines the Centers for Disease Control and Prevention public database (number of deaths) and Human Mortality Database/Current Population Survey mid-year population estimates.

- Calendar years 1989-2015
- Years of birth 1914-1970
- 2 genders
- 2 education levels
- 13 groups of causes of death (more possible too!)

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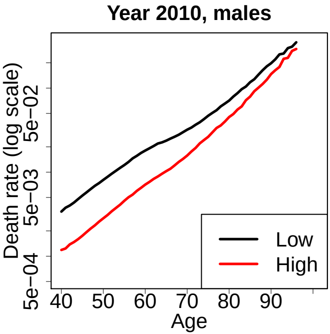
Data availability

List of causes of death:

1- Lung and bronchus cancer
2- Lifestyle cancers
3- Prostate or breast cancer
4- Other cancers
5- Chronic lower respiratory disease
6- Diabetes
7- Heart disease
8- Cerebrovascular disease
9- Other circulatory disease
10- Dementia and other mental illness
11- Accidental
12- Suicide, poisoning, and cirrhosis
13- All other

ALL CAUSE MORTALITY

A look at crude death rates



Initial/final gap males: 2.86 $\rightarrow$ 1.20
Initial/final gap females: 2.62 $\rightarrow$ 1.12

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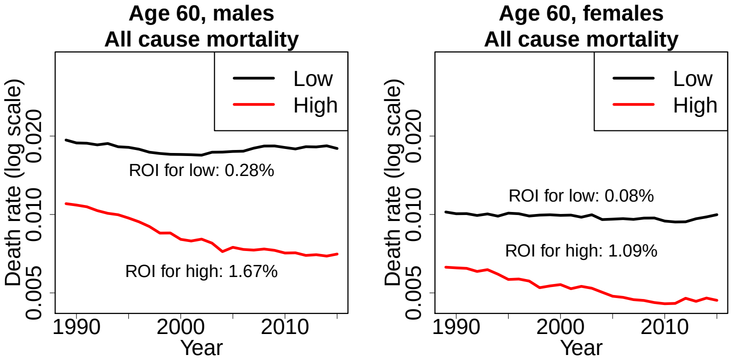
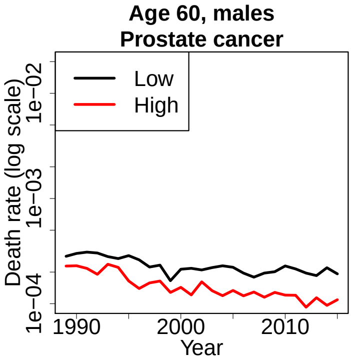
Death rates by education, age 60 by year

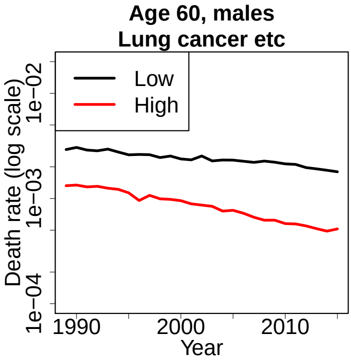


Initial/final gap males: $1.75 \to 2.54$
Initial/final gap females: $1.63 \to 2.13$

CAUSE OF DEATH MORTALITY

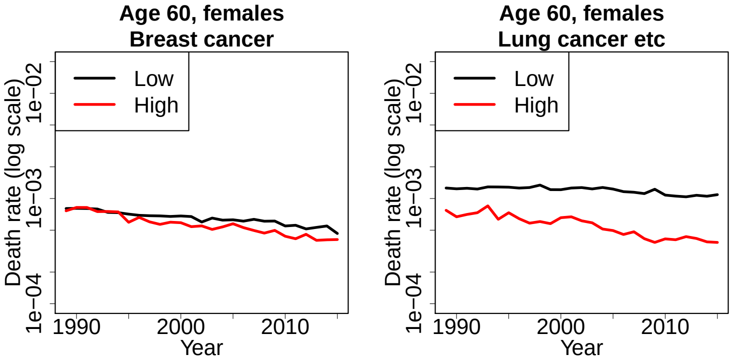
Death rates by education, age 60 by year





Initial→final ratio for prostate cancer: 1.24 → 1.76
Initial→final ratio for lung cancer: 2.21 → 3.49

Death rates by education, age 60 by year



Initial→final ratio for breast cancer: 1.05 → 1.14
Initial→final ratio for lung cancer: 1.63 → 2.84

STOCHASTIC MODELLING

Modelling

We will fit a stochastic model for the mortality rates independently to each gender, education group, and group of causes of death, for ages 50-75 and years 1989-2015.

Our goal is to identify distinct trends in the cohort effects for different causes of death that point at both the drivers behind mortality for each cause and the changing behaviours of the population analysed.

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Modelling

Model for the mortality rates $m(x,t)$:

$$D(x,t) \sim \text{Poisson}(m(x,t)E(x,t)),$$

where

$$\log(m(x,t)) = \alpha_x + \kappa_t^{(1)} + (\bar{x} - x)\kappa_t^{(2)} + \gamma_{t-x}$$

Plat model restricted to high ages.

$\gamma_{t-x} \equiv \gamma_c$ cohort effect. From a formal standpoint: mortality is a function of year of birth.

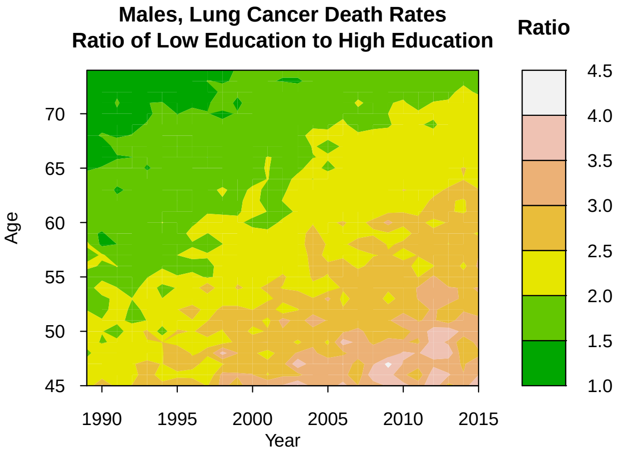
How do cohort effects arise in practice?

Non-homogeneities that are strongly linked to when a person was born, and not to the period they live in. Examples:

- Smoking
- Type of work (blue collar, white collar)
- Diet (home cooked/processed food)

Typically, health behaviours fall into this category.

Modelling



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Identifiability constraints for the Plat model:

$$\sum_t \kappa_t^{(1)} = 0, \quad \sum_t \kappa_t^{(2)} = 0, \quad \sum_c \gamma_c = 0,$$
$$\sum_c c\gamma_c = 0, \quad \sum_c c^2\gamma_c = 0.$$

All time series parameters will average to zero, and the cohort effectc will have no linear or quadratic trends!

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Modelling

Two approaches:

- Estimate the α's, κ's, and γ's from maximum likelihood, bootstrap to obtain CIs.
- Assume time series structure for γ_c, $\kappa_t^{(1)}$, and $\kappa_t^{(2)}$, and use Bayesian techniques.

For the second approach we assume:

$$\gamma_c \text{ is an } AR(2) \text{ process,}$$

$$\boldsymbol{\kappa_t} = \begin{pmatrix} \kappa_t^{(1)} \\ \kappa_t^{(2)} \end{pmatrix} \text{ is a RW with drift } \boldsymbol{\mu}.$$

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Bayesian approach

Priors for the $AR(2)$ parameters:

$$\sigma_c^2 \sim \textit{Inv-Gamma}(a, b)$$
$$\text{logit}(\rho) \sim \mathcal{N}(0, \sigma_\rho^2)$$
$$\text{logit}(\tau) \sim \mathcal{N}(0, \sigma_\tau^2)$$

Priors for the random walk:

$$\Sigma \sim \textit{Inv-Wishart}(\nu, \mathbf{S})$$
$$\mu_1 \sim \mathcal{N}(0, \sigma_{\mu_1}^2)$$
$$\mu_2 \sim \mathcal{N}(0, \sigma_{\mu_2}^2)$$

Bayesian approach

The final contributions to the log posterior are:

$$\log\left(P(\alpha_x, \kappa_t^{(1)}, \kappa_t^{(2)}, \gamma_c, \sigma_c, \rho, \tau, \Sigma, \mu_1, \mu_2 | D, E)\right) \propto$$

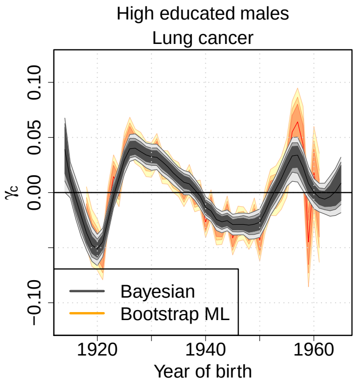
$$\ell_P + \ell_{ar\gamma} + \ell_{rw\kappa} +$$

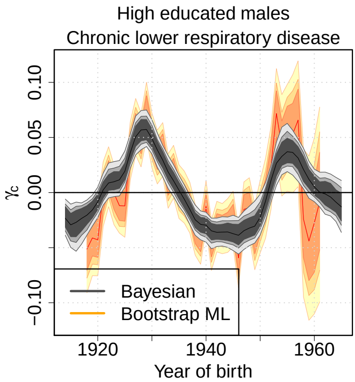
$$\log(\pi(\sigma_c)) + \log(\pi(\tau)) + \log(\pi(\rho)) +$$

$$\log(\pi(\Sigma)) + \log(\pi(\mu_1)) + \log(\pi(\mu_2))$$

Not known analytical solutions. MCMC methods required.

Cohort effects





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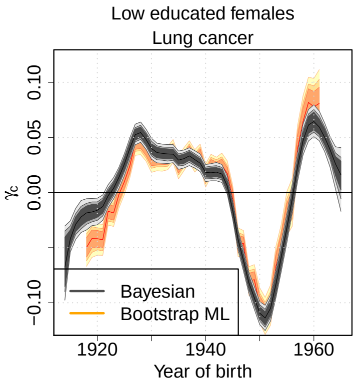
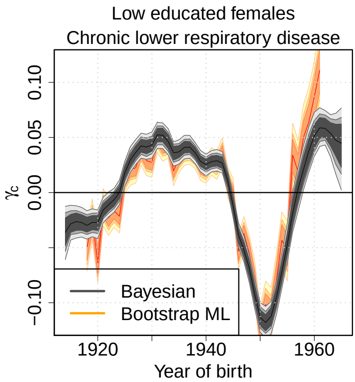
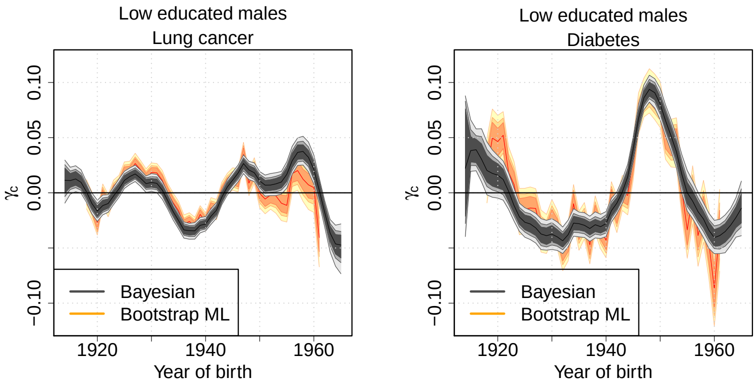
Cohort effects





Cohort effects



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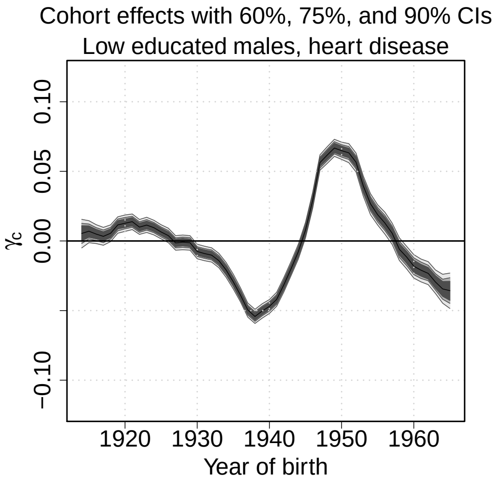
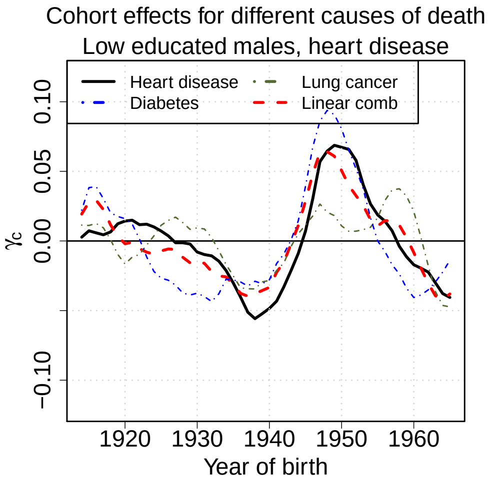
Cohort effects



Cohort effects



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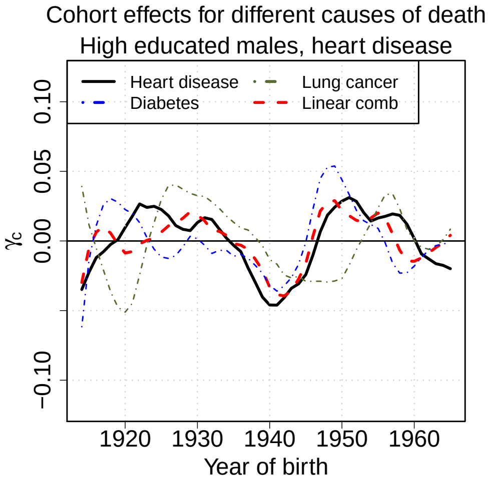
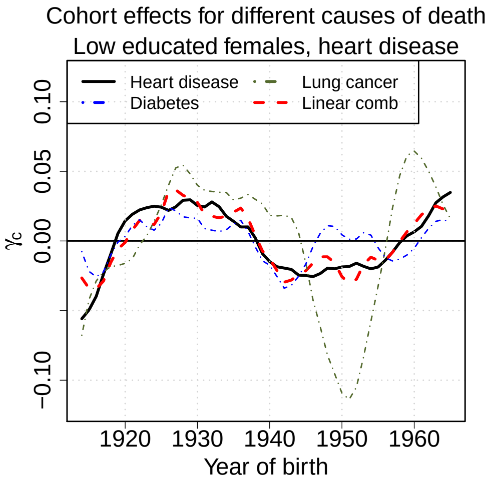
Cohort effects



Cohort effects



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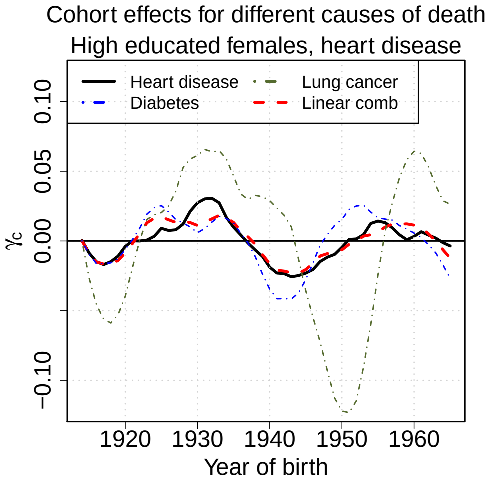
Cohort effects



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Conclusions

- → Modelling cause of death data provides insight into the reasons behind the evolution of all cause mortality.
- → The shape of the cohort effects for different causes of death is linked to different underlying risk factors.
- → Different groups show different cohort effect patterns, reflecting different health behaviours.
- → Complex interactions between lifestyle factors are behind inequalities in death rates in the US.

Future work

There are several parts of this work that can be extended in the future:

- Systematise the cohort effect analysis.
- Mortality projections.
- Applications to annuities and life insurance.
- Extension of the analysis to other populations.

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Thank You!

Questions?

Poisson log-likelihood (both approaches):

$$\ell_P \propto \sum_{x,t} \Big[-E_{xt} \exp(\alpha_x + \kappa_t^{(1)} + (\bar{x} - x)\kappa_t^{(2)} + \gamma_c) + D_{xt}(\alpha_x + \kappa_t^{(1)} + (\bar{x} - x)\kappa_t^{(2)} + \gamma_c) \Big]$$

Parameters easily estimated using R (StMoMo library). Bootstrapping techniques help obtain confidence intervals.

Random walk log-likelihood for γ_c:

$$\ell_{rw\gamma} \propto -\frac{1}{2\sigma_c^2}\sum_{c=3}^{n_c}(\gamma_c - (\rho+\tau)\gamma_{c-1} + \rho\tau\gamma_{c-2})^2$$
$$-\frac{n_c-2}{2}\log\left(\sigma_c^2\right) - \frac{1}{2}\log(\sigma_{ac}) - \frac{1}{2\sigma_{ac}}\gamma_2^2,$$

where we have used the autocovariance

$$\sigma_{ac} = \frac{1+\rho\tau}{1-\rho\tau}\frac{\sigma_c^2}{(1+\rho\tau)^2-(\rho+\tau)^2}.$$

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Random walk log-likelihood for $\boldsymbol{\kappa}_t$:

$$\ell_{rw\kappa} \propto -\frac{1}{2}\sum_{t=2}^{n_t}\left[(\boldsymbol{\kappa}_d)^T\Sigma^{-1}\boldsymbol{\kappa}_d\right] - \frac{n_t - 1}{2}\log\left(|\Sigma|\right),$$

with

$$\boldsymbol{\kappa}_d = \begin{pmatrix} \kappa_t^{(1)} - (\kappa_{t-1}^{(1)} + \mu_1) \\ \kappa_t^{(2)} - (\kappa_{t-1}^{(2)} + \mu_2) \end{pmatrix}$$

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Priors:

$$\sigma_c \sim \textit{Inv-Gamma}(10, 5 \cdot 10^{-4}),$$

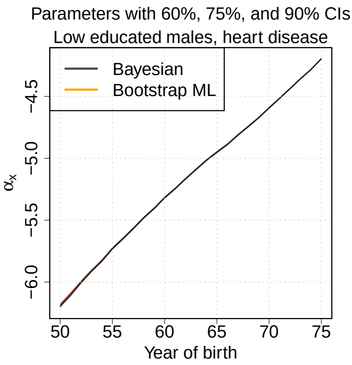
$$\Sigma \sim \textit{Inv-Wishart}\left(10, \begin{pmatrix} 10^{-4} & 0 \\ 0 & 10^{-4} \end{pmatrix}\right),$$

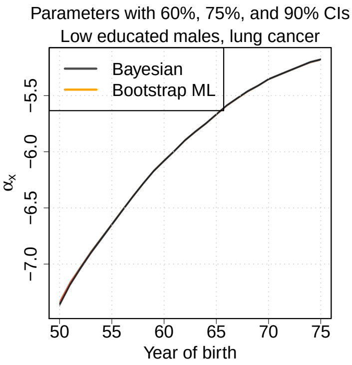
$$\mu_1 \sim \mathcal{N}(0, 1^2),$$

$$\mu_2 \sim \mathcal{N}(0, 1^2),$$

$$\text{logit}(\rho) \sim \mathcal{N}(0, 0.5^2),$$

$$\text{logit}(\tau) \sim \mathcal{N}(0, 0.5^2).$$





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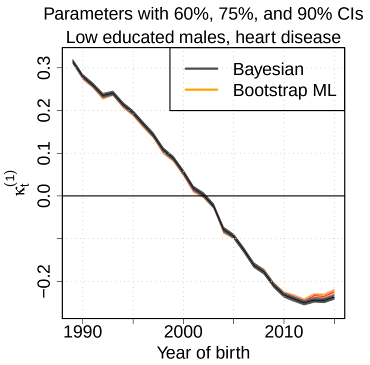
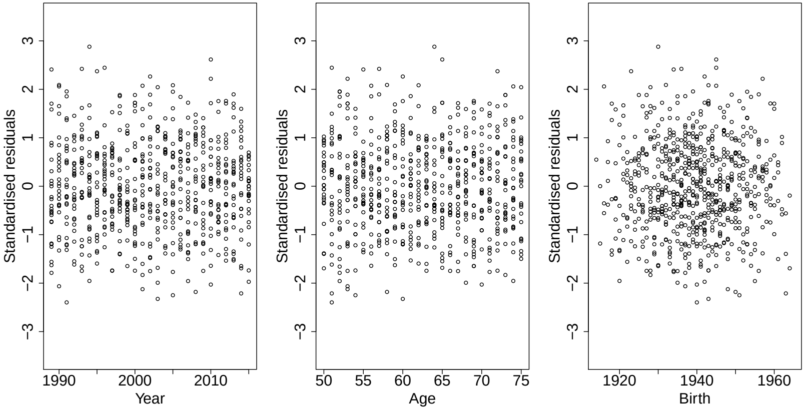
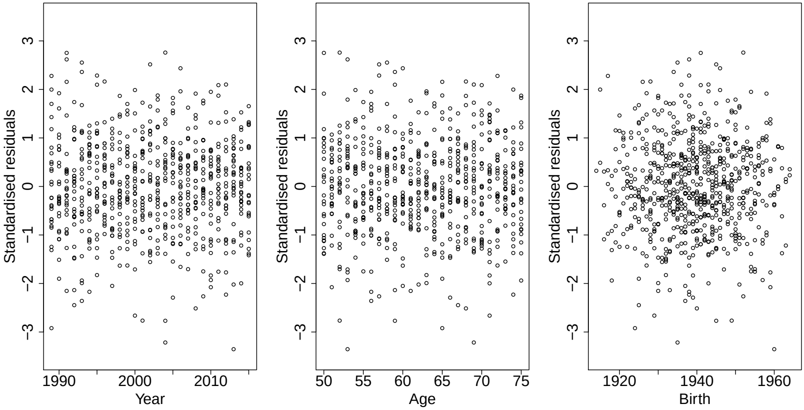

Parameters with 60%, 75%, and 90% CIs
Low educated males, heart disease
Bayesian
Bootstrap ML
$\kappa_t^{(1)}$
0.3
0.2
0.1
0.0
−0.2
1990
2000
2010
Year of birth
Parameters with 60%, 75%, and 90% CIs
Low educated males, heart disease
Bayesian
Bootstrap ML
$\kappa_t^{(2)}$
0.005
0.000
−0.005
1990
2000
2010
Year of birth

Residuals for lung cancer, low educated males



Residuals for diabetes, low educated males



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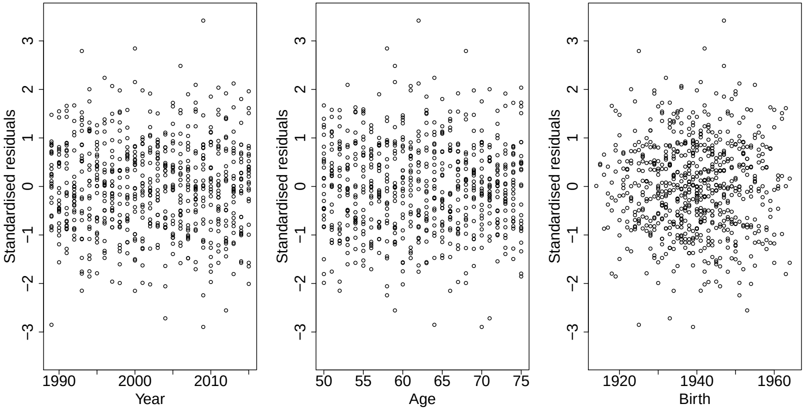
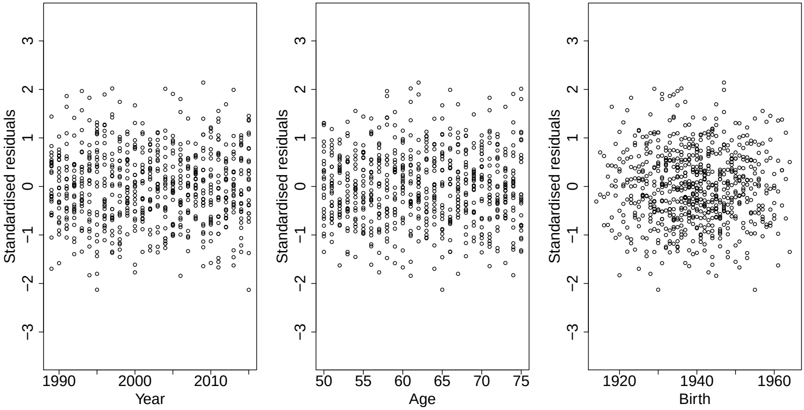
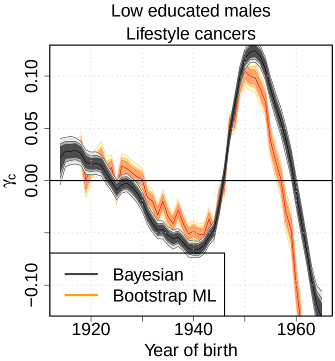
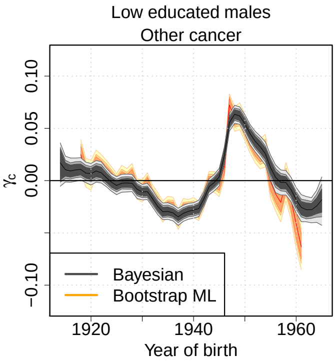
Residuals for heart disease, low educated males

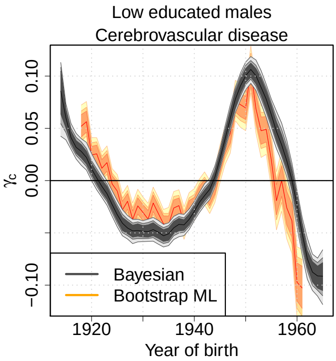


Residuals for all cause, low educated males




Low educated males
Lifestyle cancers
Low educated males
Prostate and breast cancer
γc
0.10
0.05
0.00
−0.10
1920
1940
1960
Year of birth
Bayesian
Bootstrap ML





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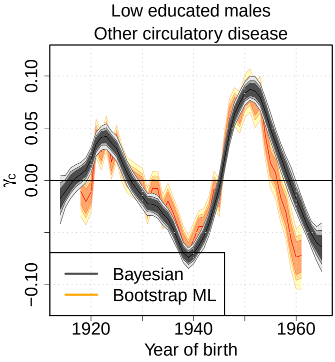
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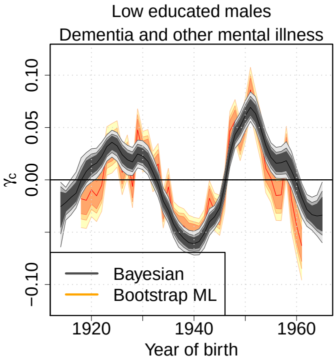
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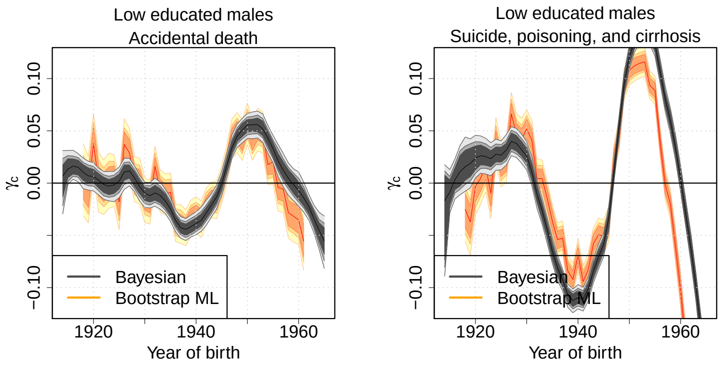

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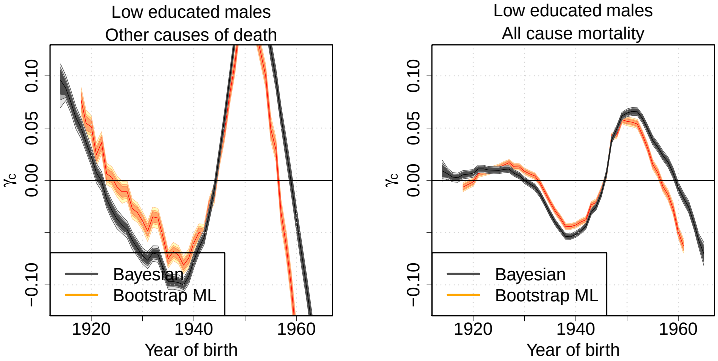

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