Exploring key drivers in cancer risk: Unveiling disparities

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Outline

1. Part 1: What we have done in the SCOR-funded project
    - (Semi-)Markov model for breast cancer
    - Summary (1)
2. Part 2: Earlier cancer-related research
    - Bayesian modelling for cancer risk
    - Insights gained from the population data of England
3. Part 3: Ongoing cancer-related research
    - Projection of cancer mortality
    - Summary (2)

Funded project:

Breast cancer (BC) as it is

- **the most common** cancer diagnosed in women
- **one of the leading causes** of death for women
- one of the most **common** conditions amongst critical illness insurance (CII) claims, e.g. 44% of female CII claims in 2014 in the UK

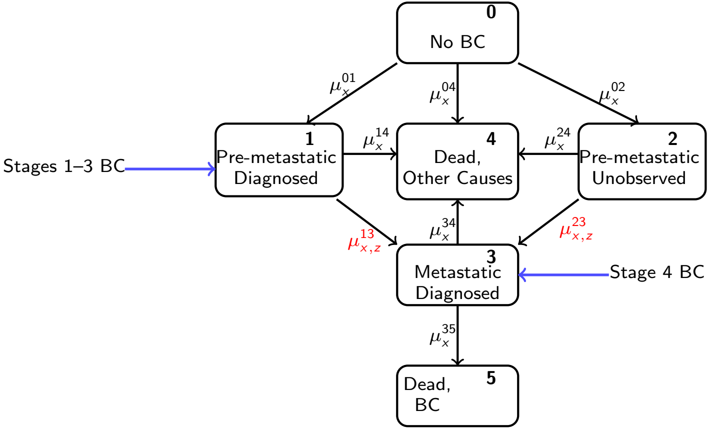
Investigating BC rates in the presence of:

- major disruptions to health services, particularly caused by a catastrophic event, e.g. the COVID-19, preventing or delaying the diagnosis of BC

Examining the related insurance products:

- actuarial fair premiums

A versatile semi-Markov model



- Duration dependence in ‘Pre-metastatic Diagnosed’ and ‘Pre-metastatic Unobserved’
- No treatment in ‘Pre-metastatic Unobserved’ $\Rightarrow \mu_{x,z}^{13} < \mu_{x,z}^{23}$

Summary (1)

1. A valuable model relating to delays in the provision of BC diagnostic and treatment services

   . . . also relevant to meet the needs of women with medical history of BC

2. As compared to the pre-pandemic scenario

   – 3–6% increase in deaths from BC

   – 5–8% increase in deaths from other causes

   between ages 65–89

3. Flexible models are relevant to medical underwriting of related insurance contracts

4. Duration dependence matters in actuarial applications

Cancer data

Cancer incidence and deaths data
England: Office for National Statistics (ONS)

- Age groups: 0, 1-4, 5-9, ..., 95+

  Age-standardised results, based on the European Standard Population (ESP) 2013

- Gender

- Years: 2001–2018 (*some* up to 2022)

- Income Deprivation deciles or quintiles

  1: most deprived; 10: least deprived

  1: most deprived; 5: least deprived

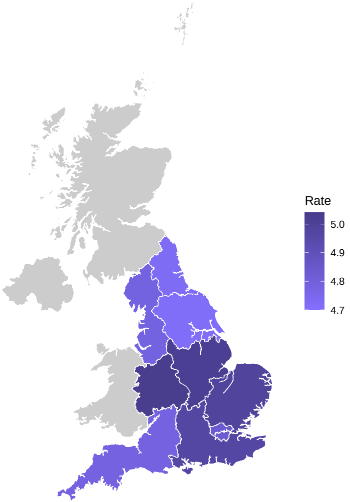
- Regions of England: North East, North West, Yorkshire and the Humber, East Midlands, West Midlands, East, London, South East and South West

A separate stochastic modelling: Bayesian models for cancer rates

$$C_{a,t,d,g,r} \sim \text{Poisson}(\theta_{a,t,d,g,r} \; E_{a,t,d,g,r})$$
$$\theta_{a,t,d,g,r} \sim \text{Lognormal}(\mu_{a,t,d,g,r}, \sigma^2)$$
$$\mu_{a,t,d,g,r} = \boldsymbol{\beta}' \boldsymbol{X}$$
$$\boldsymbol{\beta}\text{'s} \sim \text{Normal}(0, 10^4)$$ **[vague priors for risk factor effects]**
$$\sigma^2 \sim \text{Inv.Gamma}(1, 0.001)$$

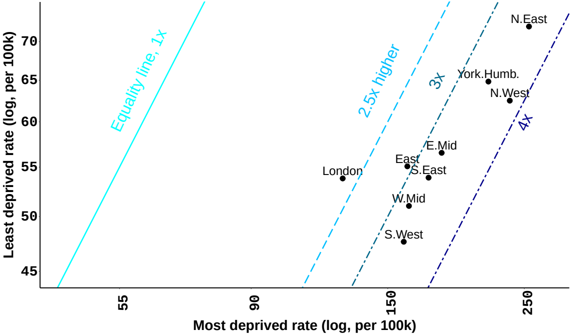
- $C_{a,t,d,g,r}$: number of cancer registrations/deaths at **age** a, in **year** t, for **gender** g, **deprivation** level d and **region** r
- $E_{a,t,d,g,r}$: mid-year population estimates
- $\theta_{a,t,d,g,r}$: incidence/mortality rates
- $\boldsymbol{X}$: vector of covariates: **age**, **year**, **deprivation**, **gender**, **region**, average age-at-diagnosis (AAD) + appropriate interaction(s)
- $\boldsymbol{\beta}$: vector of coefficients

Regional variation: BC mortality, 2018



✓Rate is per 10K
✓Deprivation is not significant

Most v. least deprived by region: LC mortality, women, 2017



- A life-style cancer
- Rates for **most deprived** much higher
- Regional variation

What insights we gain: (Arık et al., 2020, 2021, 2022)

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Health

Study points to big surge in under-50 cancer cases

6 September · Comments

The number of cancer cases among the under-50s around the world appears to have risen sharply in the past 30 years, a study suggests.

- **Age:** higher rates at older ages?
  - changing?
  - lifestyle factors?
- **Time:**
  - higher incidence in more recent years
  - lower mortality
- **Gender:** higher rates for men
- **Regional inequality** exists
- **Socio-economic differences** are more relevant to life-style cancers

A separate related research: Bayesian forecasting for cancer mortality

$$C_{a,t,d,g,r} \sim \text{Poisson}(\theta_{a,t,d,g,r}\ E_{a,t,d,g,r})$$

$$\theta_{a,t,d,g,r} \sim \text{Lognormal}(\mu_{a,t,d,g,r}, \sigma^2)$$

$$\mu_{a,t,d,g,r} = \beta_0 + \beta_{1,a} + \beta_{2,t} + \beta_{3,r} + \beta_{4,d} + \beta_5 \text{AAD}_{r,d} + \beta_6 \text{NS}_{a,t-20} + \text{interaction terms}$$

$$\beta' \sim \text{Normal}(0, 10^4) \quad \text{[vague priors for risk factor effects]}$$

$$\sigma^2 \sim \text{Inv.Gamma}(1, 0.1)$$

Add random walk with drift for ‘period’ effect:

$$\beta_{2,t} = \text{drift} + \beta_{2,t-1} + \epsilon_t$$

$$\text{drift} \sim \text{Normal}(0, \sigma^2_{\text{drift}})$$

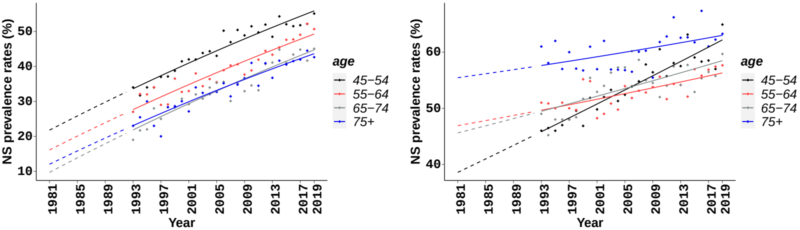
$$\epsilon_t \sim \text{Normal}(0, \sigma^2_{\beta_2})$$

$$\sigma^2_{\beta_2} \sim \text{Inv.Gamma}(1, 0.001)$$

for $t = 2002, \ldots, 2036$, where $\hat{\sigma}^2_{\text{drift}} = \frac{\hat{\sigma}^2_{\beta_2}}{2018-2001}$

Non-smoker prevalence rates: England, 1993–2019

Non-smoker (NS) prevalence observed **(dots)** and fitted **(solid line)** rates for men **(left)** and women **(right)**



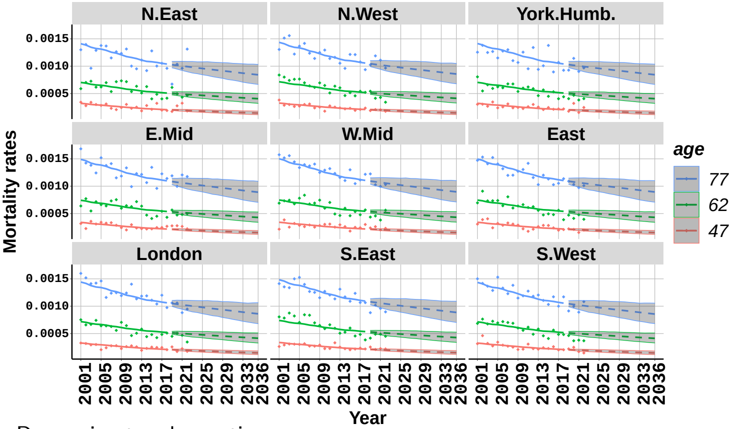
Increasing trend for NS prevalence

. . . more evident in men

Reconstruct NS prevalence **(dashed)** backwards to 1981:

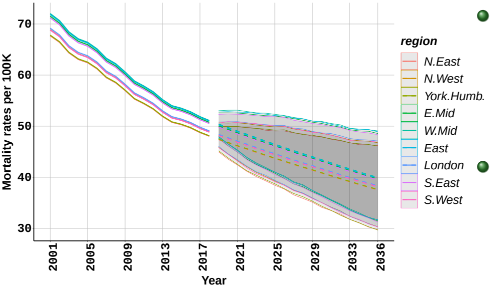
$$\mathrm{NS}_{a,t} = \beta_0 + \beta_{1,a} + \beta_2 t + \beta_3 t^2 + \beta_{4,a} t$$

Projected mortality: BC, women, 2001–2036



- Decreasing trend over time
- AAD is *NOT* significant BUT smoking is
- Projected rates for youngest & oldest screening age groups *NOT* overlapping

Regional gap: BC, women, 2001–2036



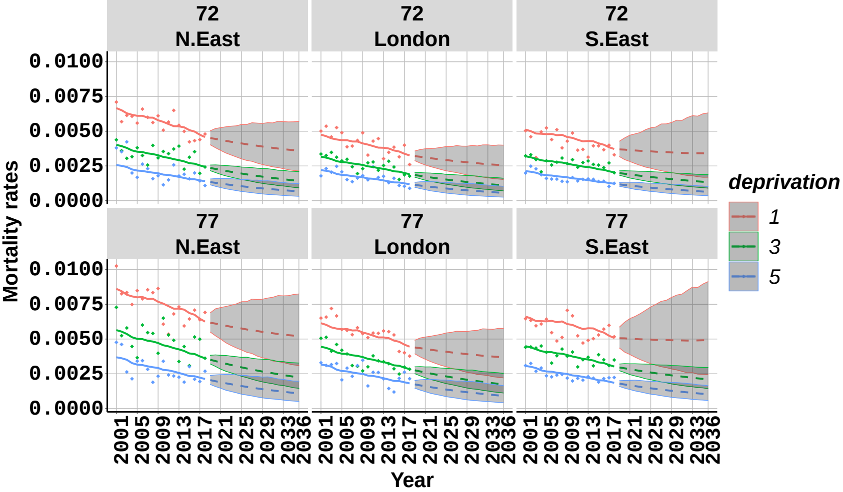
- Significant improvement in mortality from 2001 to 2018

  ... and persists in the future years

- Region is significant

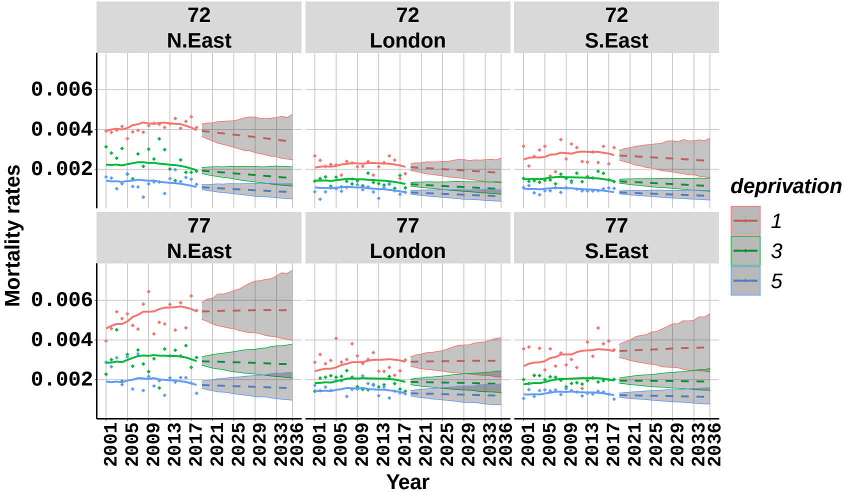
  ... yet ONLY marginal differences in mortality across regions

Projected mortality: LC, men, 2001–2036



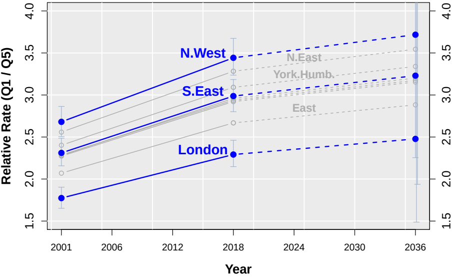
- Deprivation *quintiles*
- Projected rates for most & least deprived *NOT* overlapping

Projected mortality: LC, women, 2001–2036



- Deprivation *quintiles*
- Mortality for women *NOT* always decreasing

Deprivation gap: LC, women, 2001–2036



- Widening deprivation gap from 2001 to 2018

  ...persists in the future years

- Relative mortality rate

$$\frac{\hat{\theta}_{t,\text{quintile } 1,r}}{\hat{\theta}_{t,\text{quintile } 5,r}}$$

- $\hat{\theta}_{t,d,r}$: age-standardised fitted mortality rates

- Comparable findings in men

Impact of diagnosis delays on mortality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Scottish cancer cases rise by 15% after pandemic drop

28 March

GETTY IMAGES

Breast cancer screening was paused in 2020 due to the Covid-19 pandemic

Cases of cancer in Scotland increased by almost 15% in a year after dropping in the first 12 months of the pandemic.

- Estimate average age-at-diagnosis (AAD) with incidence rates

$$\mathrm{AAD}_{t,d,g,r} = \frac{\sum_a a\hat{\lambda}_{a,t,d,g,r} E_a^{\mathrm{std}}}{\sum_a \hat{\lambda}_{a,t,d,g,r} E_a^{\mathrm{std}}}$$

$$\mathrm{AAD}_{d,g,r} = \frac{\sum_t \mathrm{AAD}_{t,d,g,r} E_{t,d,g,r}}{\sum_t E_{t,d,g,r}}$$

- $\hat{\lambda}_{a,t,d,g,r}$: fitted incidence rates

- Include AAD as risk factor in mortality model
  e.g.
  $\mu_{a,t,d,r} = \beta_0 + \beta_{1,a} + \beta_{2,t} + \beta_{3,r}$
  $+\beta_{4,d} + \beta_5 \mathrm{AAD}_{d,r} + \beta_6 \mathrm{NS}_{a,t-20}$

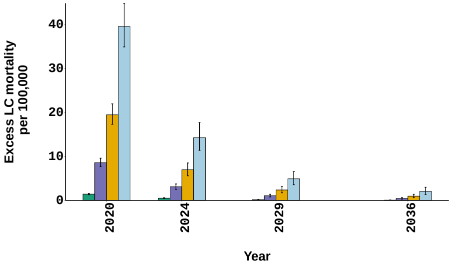
- Estimate impact on mortality

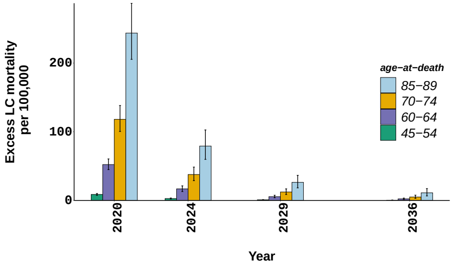
Quantify COVID-19 impact on future mortality

- Assume increase in AAD from 2020
  - Use ONS region-based future population estimates
  - Assume future deprivation structure unchanged
  - The impact of an increase in AAD distributed over future years

- Fit Bayesian forecasting model:
  - under no change in AAD (baseline scenario)
  - under 1-month AAD increase (COVID scenario 1)
  - under 3-month AAD increase (COVID scenario 2)
  - under 6-month AAD increase (COVID scenario 3)
  - estimate excess deaths

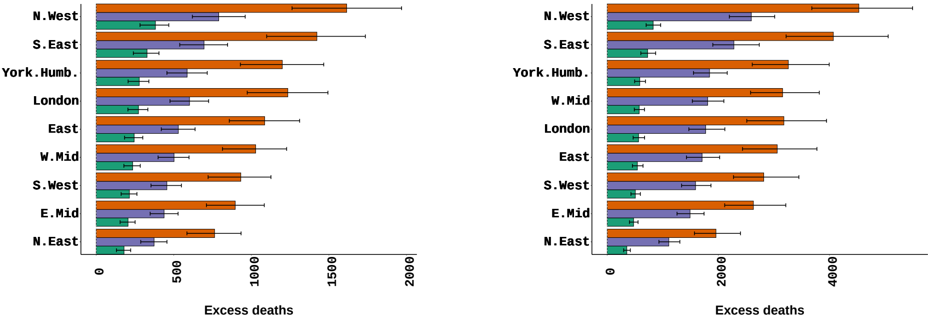
Excess mortality by age: LC, men, 2020–2036





- Annual excess mortality due to 1-month **(left)** and 6-month **(right)** diagnosis delays
- LC is the leading cause of death for ages 65 to 79 (ONS, 2023)

Total excess deaths by region: LC, 2020–2036

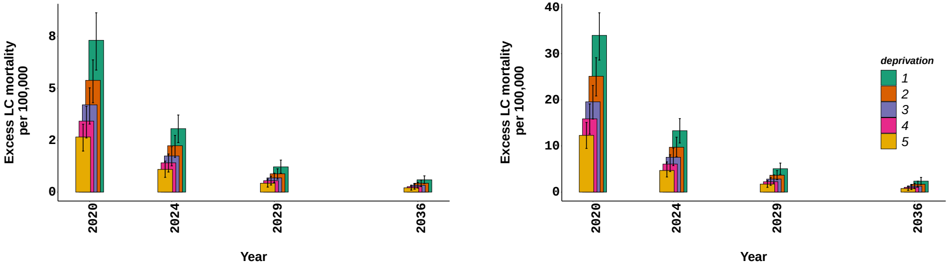


Excess deaths due to 6-month diagnosis delay:

10,180 [7,944 to 12,340] **(women)** v.
28,660 [23,040 to 35,090] **(men)**

- Excess deaths in women (left) and men (right) due to 1-month, 3-month, and 6-month delays
- Excess mortality differs by region & deprivation

Excess mortality by deprivation: LC, women, 2020–2036



- Annual excess mortality due to 1-month **(left)** and 6-month **(right)** diagnosis delays
- Higher excess mortality in the most deprived quintile

Summary (2)

1. Regional and socioeconomic gap for cancer rates is widening in England

   ... but not for all cancer types

2. Smoking is significant to explain both BC and LC mortality

3. COVID-related delays in diagnoses can lead to significant increase in cancer deaths

   – age, region and deprivation dependent

4. Projection for LC mortality shows persistent deprivation gap

   – and significant excess deaths due to COVID-like disruptions

More details in:

1. Arık, A. Estimation and projection of cancer mortality in England, SA0 project.
2. Arık, A., Cairns, A., Dodd, E., Macdonald, A.S., Shao, A., Streftaris, G. Insurance pricing for breast cancer under different multiple state models, working paper.
3. Arık, A., Cairns, A., Dodd, E., Macdonald, A.S., Streftaris, G. The effect of the COVID-19 health disruptions on breast cancer mortality for older women: A semi-Markov modelling approach, https://arxiv.org/abs/2303.16573.
4. Arık, A., Cairns, A., Dodd, E., Macdonald, A.S., Streftaris, G. Estimating the impact of the COVID-19 pandemic on breast cancer deaths among older women, Living to 100 Research Symposium, 16 February 2023, conference monograph.
5. Arık, A., Dodd, E., Cairns, A., Streftaris, G. Socioeconomic disparities in cancer incidence and mortality in England and the impact of age-at-diagnosis on cancer mortality, PLOS ONE, 2021.
6. Arık, A., Dodd, E., Streftaris, G. Cancer morbidity trends and regional differences in England - a Bayesian Analysis, PLOS ONE, 2020.

Thank You!

Questions?

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