Bayesian analysis of cancer mortality: socioeconomic disparities, COVID-19 impact and future outlook

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joint work with Andrew Cairns and George Streftaris

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Estimating The Impact Of The COVID-19 Pandemic On Breast Cancer Deaths - An Application On Breast Cancer Life Insurance – SCOR Foundation for Science

Outline

1. Trends in cancer rates over time

   – mainly lung cancer (LC) and breast cancer (BC)

2. Stochastic modelling for cancer rates

3. Variation by region and deprivation

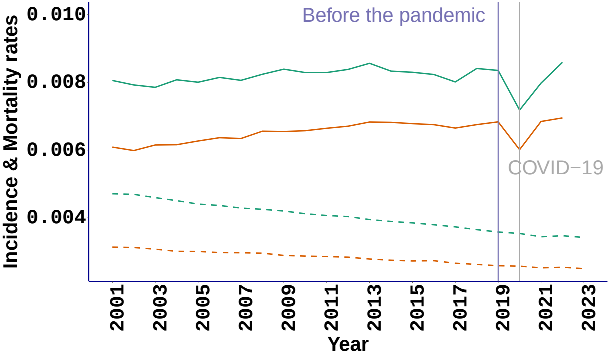
4. Mortality projection into the future

5. Change in cancer rates during COVID years

6. Impact of diagnosis delays on cancer mortality

All-cancer rates:
Trend over time, 2001–2023

Age-standardised (no modelling) incidence **(solid line)** and mortality **(dashed)** rates for men (green) and women (red)



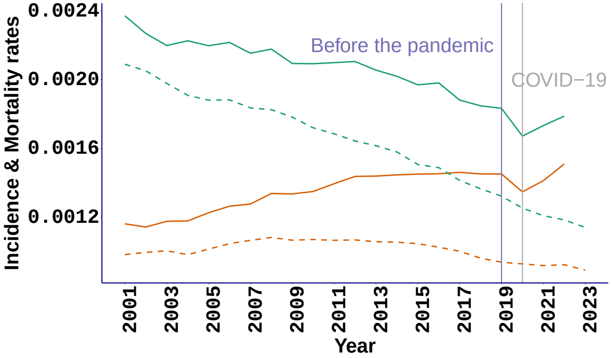
Increasing trends for incidence

Decreasing mortality trends

Higher rates for men

Notable exception in trend: LC, 2001–2023

Age-standardised (no modelling) incidence **(solid line)** and mortality **(dashed)** rates for men (green) and women (red)



Decreasing incidence for men

Increasing for women

Mortality relatively close to morbidity

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 2023)

- 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

The Index of Multiple Deprivation: IMD 2015

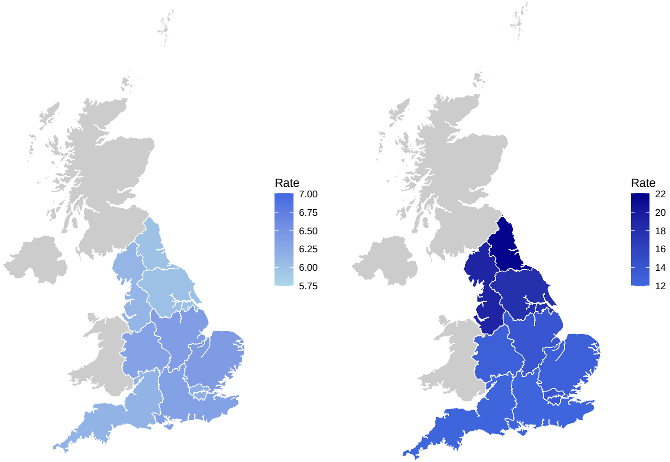
The IMD is a weighted combination of seven indices of deprivation:

- Income (22.5%)
- Employment (22.5%)
- Education (13.5%)
- Health (13.5%)
- Crime (9.3%)
- Barriers to housing and services (9.3%)
- Living environment (9.3%)

Regional variation: Cancer mortality, 2018

(a) Breast cancer

(b) Lung cancer

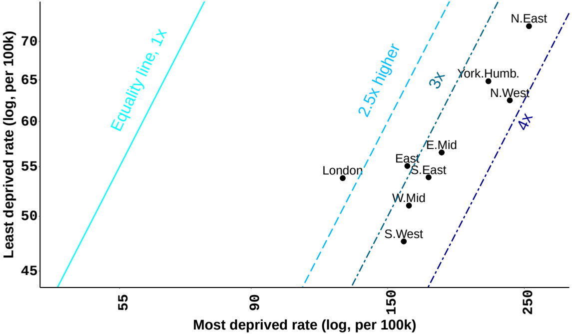


Also socio-economic differences for LC

Is variation getting better? Worse?

What is the future outlook?

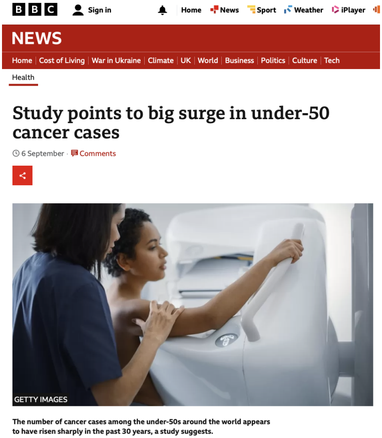
Most v. least deprived by region: LC mortality, women, 2018



Income deprivation: (1) most deprived and (10) least deprived

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

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



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Health

Study points to big surge in under-50 cancer cases

6 September · Comments

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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

Bayesian forecasting for cancer mortality

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

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

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

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

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

- **Add random walk with drift for 'period' effect:**

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

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

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

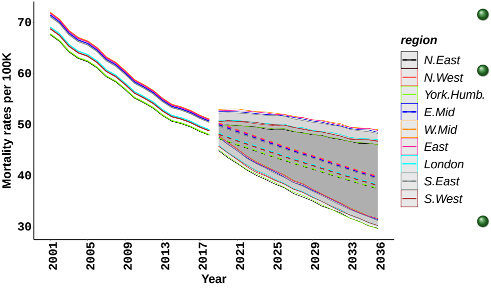
$$\sigma^2_{\beta_2} \sim \text{Inv.Gamma}(1, 0.001)$$

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

- $\text{NS}_{a,t-20}$: non-smoking prevalence

  – fitted model, 20-year lag

Regional gap:
BC, women, 2001–2036

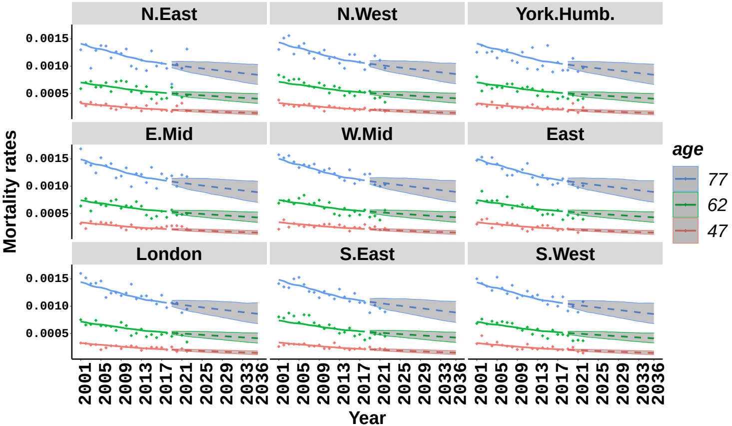


- Age-standardised mortality rates
- Significant improvement in mortality from 2001 to 2018

  . . . and persists in the future years
- Region is significant

  . . . yet ONLY marginal differences in mortality across regions

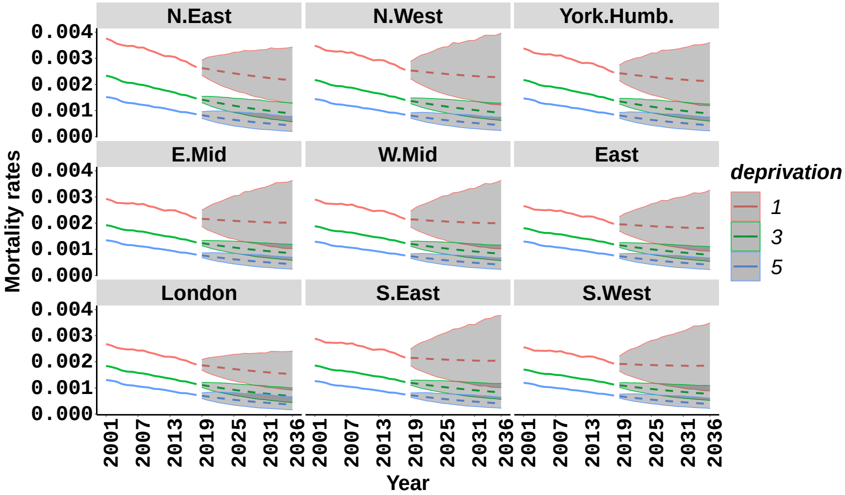
Projected mortality: BC, women, 2001–2036



- Projected rates for youngest & oldest screening age groups *NOT* overlapping

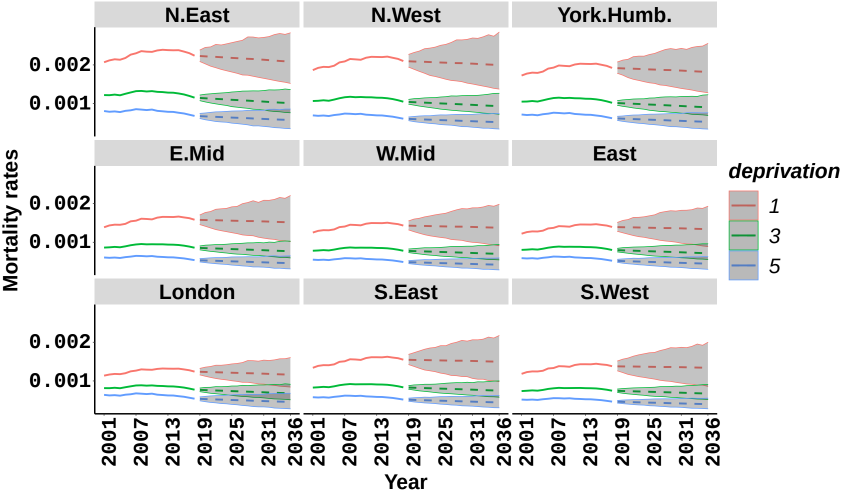
  . . . significant differences across the screening age groups

Projected mortality: LC, men, 2001–2036



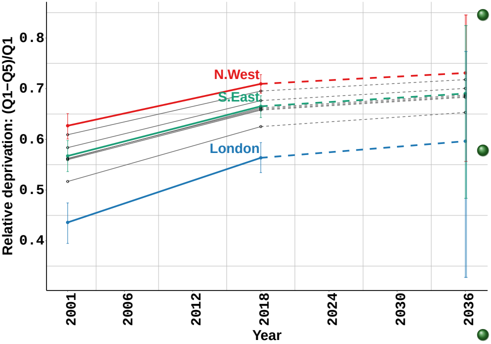
- Age-standardised mortality rates in (1) most deprived . . . (5) least deprived
- Projected rates for most & least deprived *NOT* overlapping

Projected mortality: LC, women, 2001–2036



- Age-standardised mortality rates
- Mortality for women *NOT* always decreasing

Deprivation gap:
LC, women, 2001–2036



- Increasing deprivation gap from 2001 to 2018

  ...persists in the future years

- Relative deprivation gap

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

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

- Comparable findings in men

Short-term variations: LC and BC deaths, 2020–2022

Ratio: Registered deaths/Expected deaths

- 2% marginal decline in **LC deaths for women** across England

  ...3–6% marginal increase in the East and West Midlands, and the south west of England

  ...2–7% marginal increase at ages 70 to 89

- 4% marginal decline in **LC deaths for men** in England

  ...3% marginal increase at ages 80 to 84

- 1% marginal decline in **BC deaths** in England

  ...1–5% marginal increase in the north east of England, Yorkshire and the Humber, the East Midlands

  ...10–13% increase at ages 80 to 89

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

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

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

- $\hat{\lambda}_{a,t,d,g,r}$: fitted incidence rates
- Include AAD as risk factor in mortality model
  e.g.
  $\mu_{a,t,d,r} = \beta_0 + \beta_{1,a} + \beta_{2,t} + \beta_{3,r}$
  $+\beta_{4,d} + \beta_5 \text{AAD}_{d,r} + \beta_6 \text{NS}_{a,t-20}$
- Estimate impact on mortality

Quantify the impact of delays on future mortality

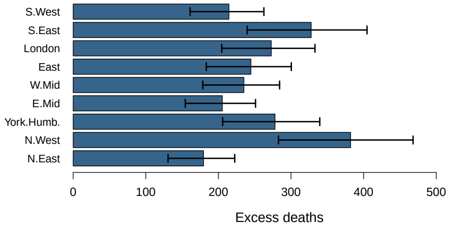
- Assume increase in AAD from 2020
  - Use ONS region-based future population estimates
  - Assume future deprivation structure unchanged
  - The impact of an increase in AAD distributed over future years

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

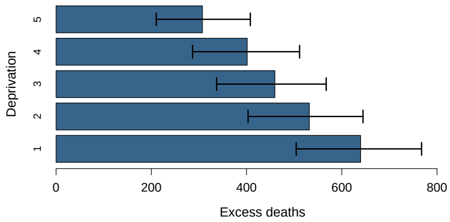
  expected death in a given scenario -
  expected death in the baseline scenario

Total excess deaths, 1-month increase in AAD: LC, women, 2020–2036

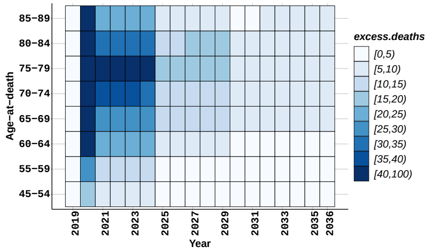
By region:



By deprivation:



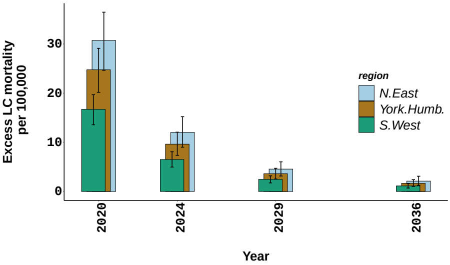
By age & year:

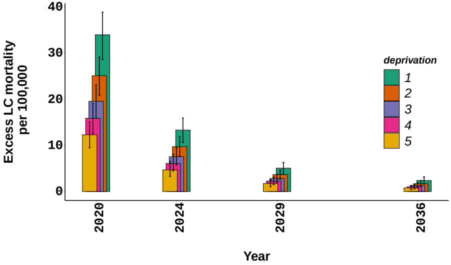


Total excess deaths: 2,340

(95% CI: 1,743 – 2,869)

Annual excess mortality: LC, women, 2020–2036





- Annual excess mortality by region **(left)** and deprivation **(right)**
- **Total excess deaths due to** 6-month AAD increase: 10,180 (95%: 7,944 – 12, 340)

Summary

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 disruptions lead to significant changes in cancer deaths

   . . . age and region dependent

4. Projection for LC mortality shows persistent deprivation gap

   . . . and significant excess deaths associated with COVID-like disruptions

Implications of this study

- New medical technologies and early cancer diagnoses improve cancer survival
- Flexible and more detailed models are relevant to medical underwriting of related insurance contracts
- Quantifying disparities can help insurers understand how insured portfolios differ from general population
- Time trends and changes important in long-term pricing and reserving
- Upcoming pandemics?
- Cancer surge among under 50s: insured ages?

More details in:

1. Arık, A., Cairns, A., Streftaris, G. Cancer mortality projection: disparities, COVID-19, and late diagnosis impact, https://arxiv.org/abs/2405.05643.
2. 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, Scandinavian Actuarial Journal, 2024.
3. 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.
4. 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.
5. 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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