# Estimating the impact of the COVID-19 pandemic on breast cancer: an application to life insurance

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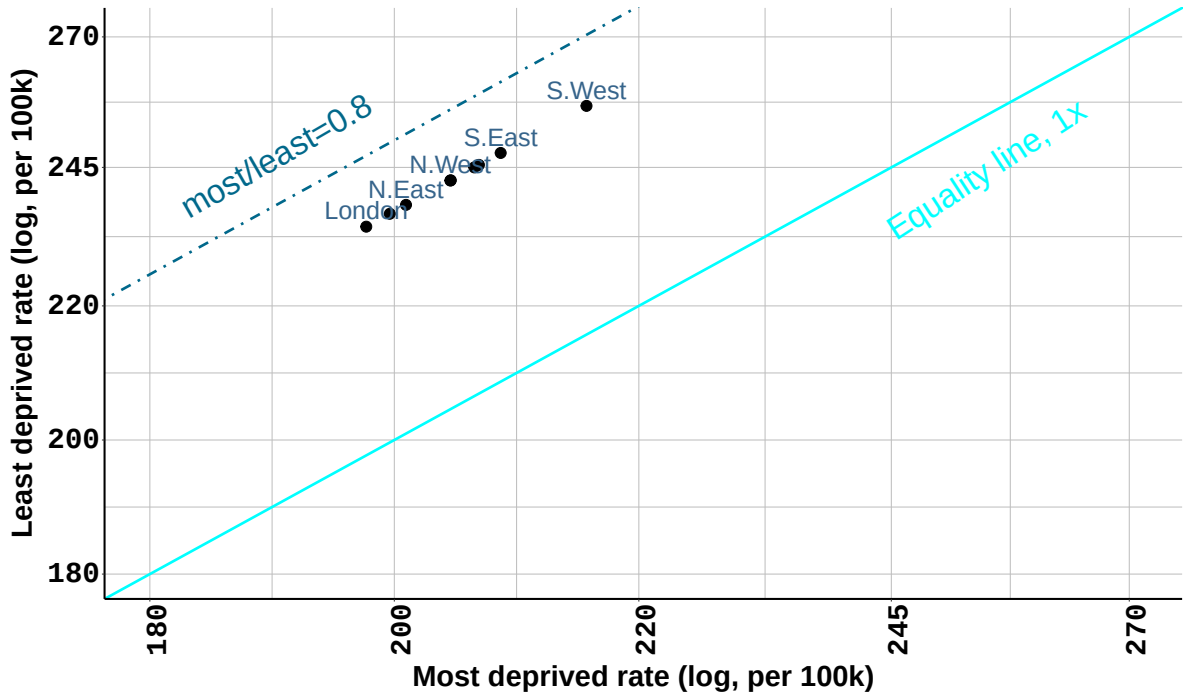
# Outline

# Motivation: why breast cancer?

Breast cancer (BC) is

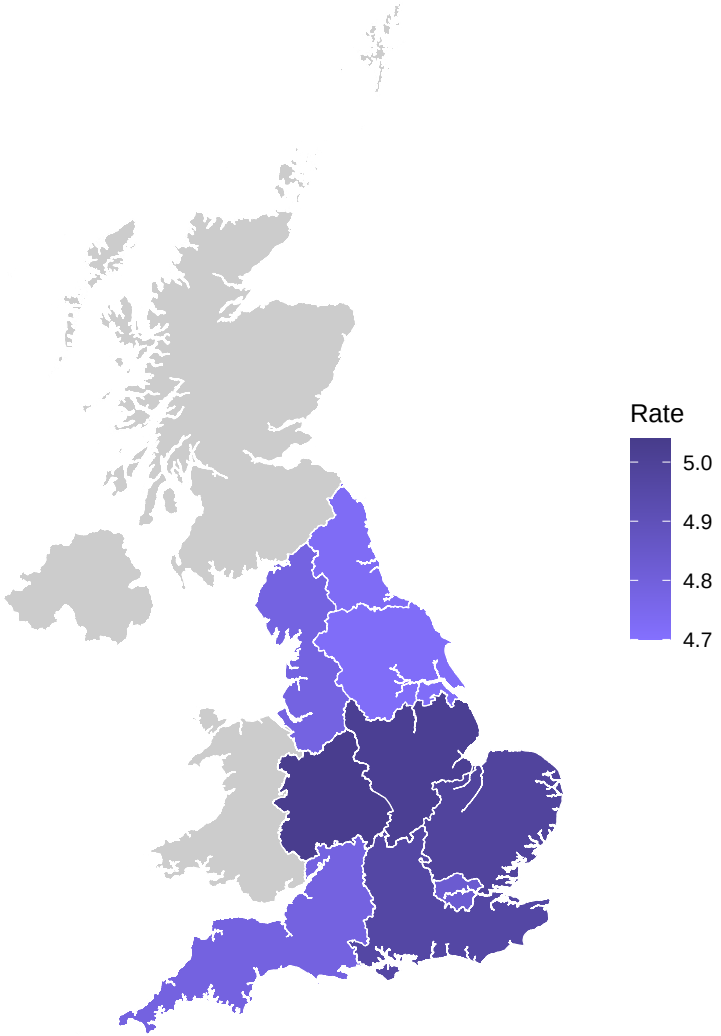
- **the most common** cancer diagnosed in women
- **one of the leading causes** of death for women
- one of the most **common** conditions amongst critical illness insurance (CII) claims, e.g. 44% of female CII claims in 2014 in the UK
- one of the cancer types where a national cancer screening programme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

# Most v. least deprived by region: BC incidence in England - 2017




- Not a life-style cancer
- Rates for least deprived higher (higher screening?)
- Less regional variation as compared to, e.g., lung cancer

# Regional variation:
# BC mortality in England - 2019




✓Rate is per 10K
✓Deprivation is not significant

# What insights we gain from BC data

- **Socio-economic differences** are less relevant as compared to, e.g., lung cancer incidence/mortality
- **Not** (easily) controllable or preventable risk factors
- **Regional inequality** exists but relatively low
  - High BC screening awareness
  - National BC screening programme for ages 47–73
- The availability of BC screening is crucial for early diagnosis, as BC can be curable

# Part 1: The impact of COVID-19 on breast cancer

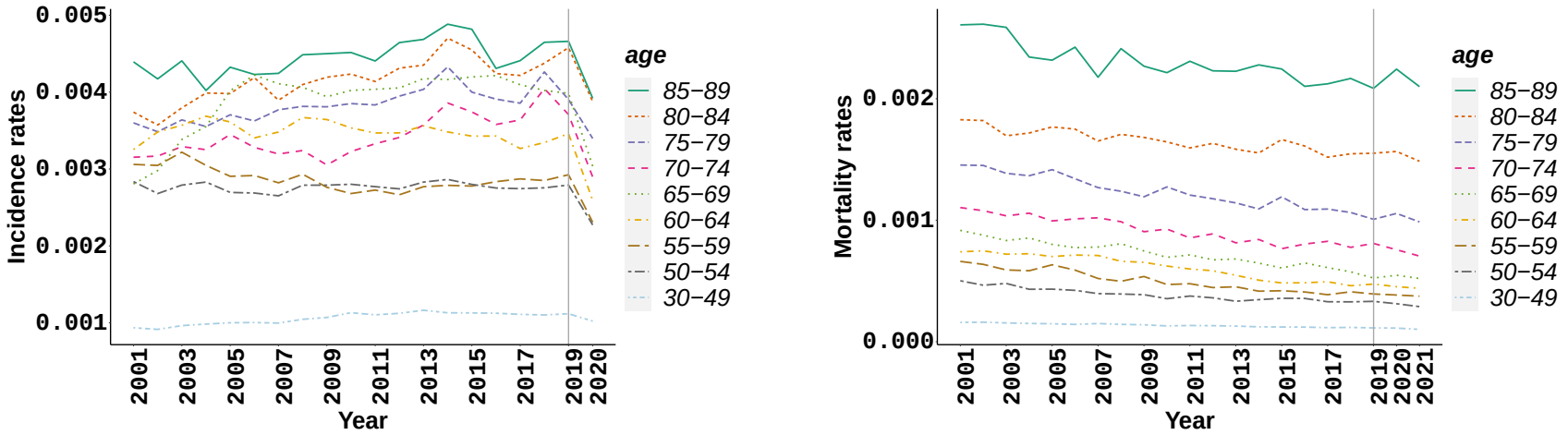
Investigate BC rates in the presence of:

- major disruptions to health services,

  particularly caused by a catastrophic event, e.g. the COVID-19,

  preventing or delaying the diagnosis of BC

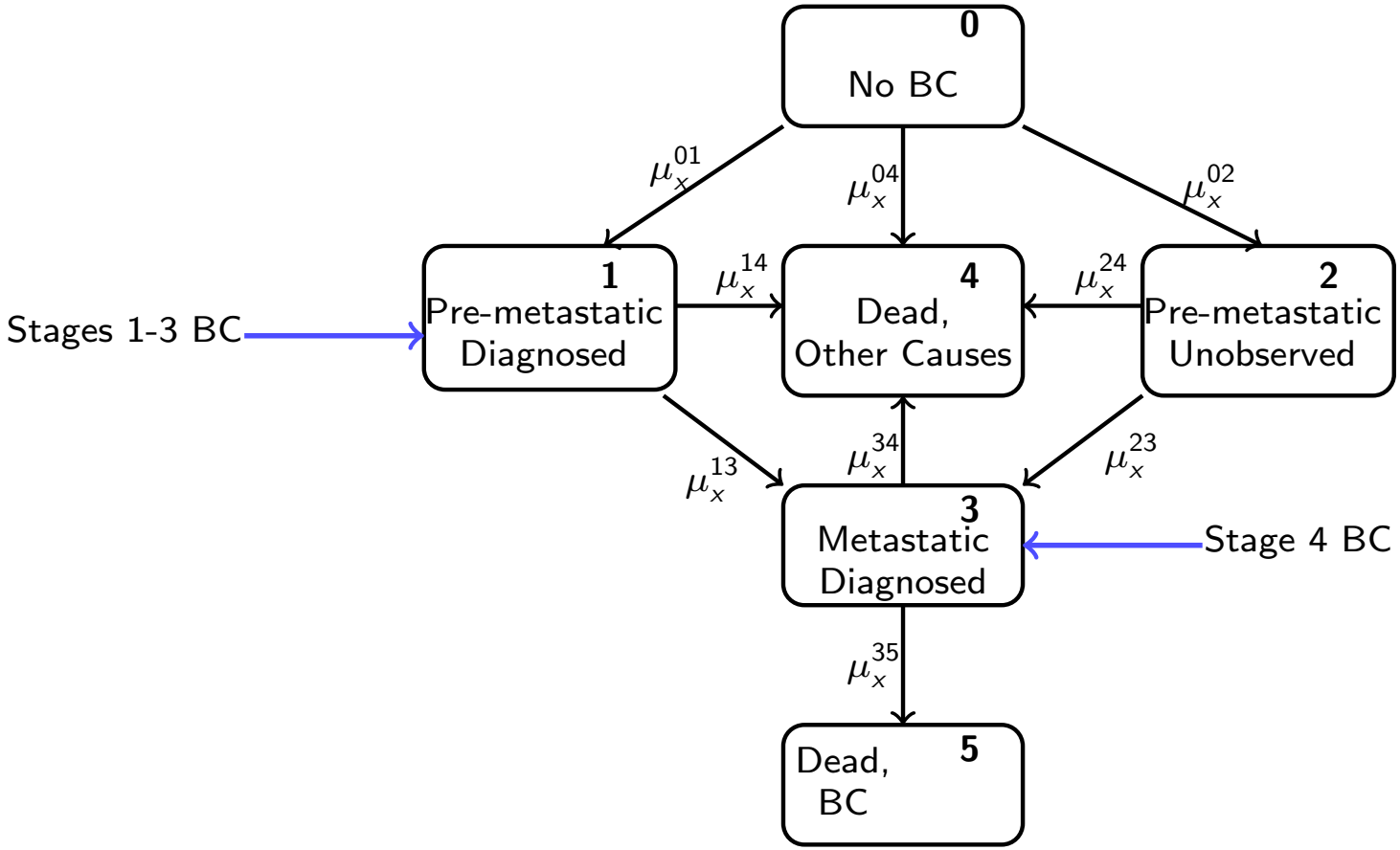
# BC incidence and mortality in England: COVID years




Incidence (left) v. Mortality (right)

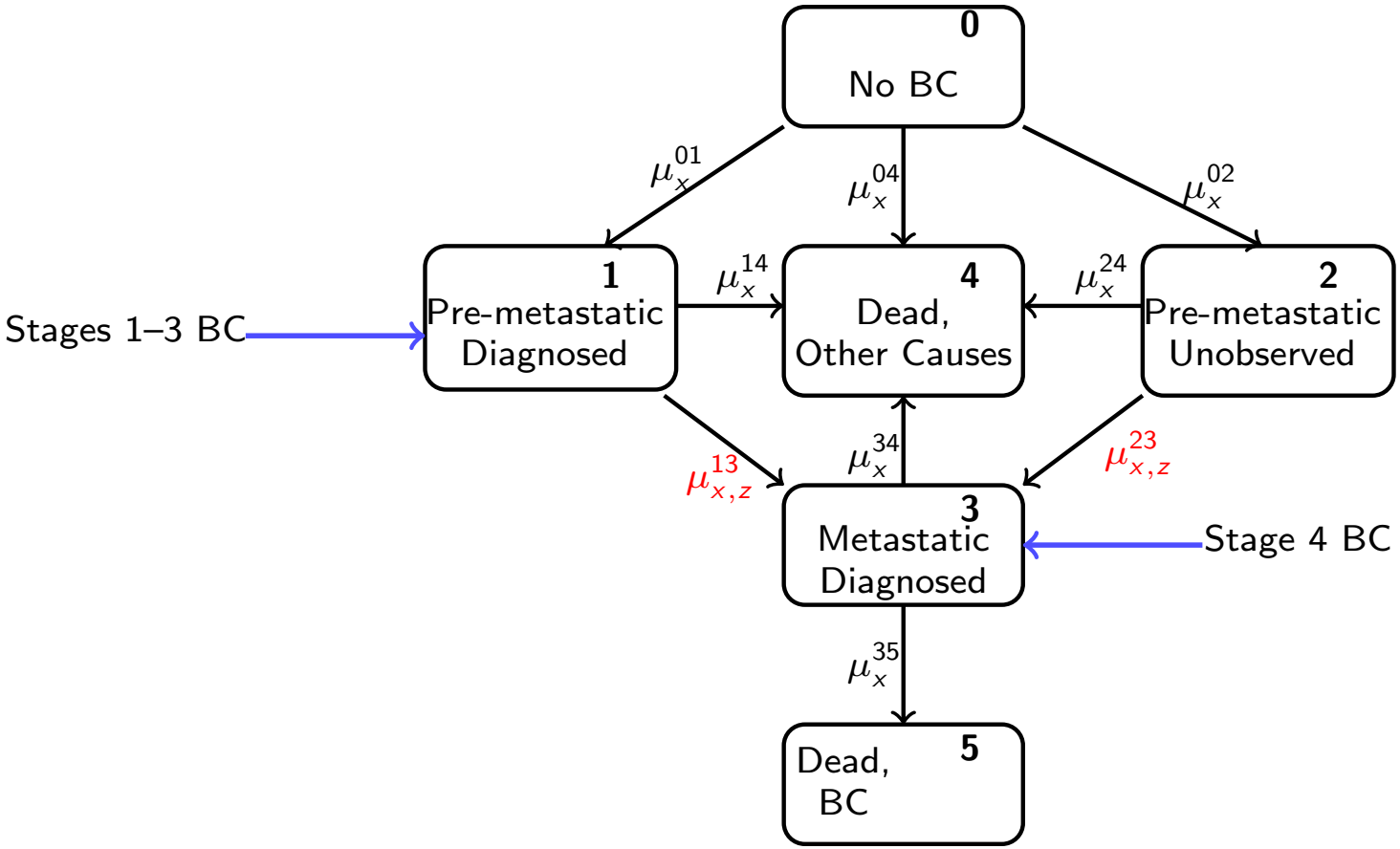
- A significant decline in BC incidence, as low as 25% at ages 60–64, in 2020 as compared to the same period in 2019
- An increase in BC mortality from ages 65+, as high as 7%, in 2020 as compared to the same period in 2019

# Multi-state model for BC transitions: Markov model




- 'Dead from BC' is only accessible from 'Metastatic Diagnosed'
- Onset of BC remains unchanged $\Rightarrow \mu_x^{01} + \mu_x^{02} = \mu_x^{*}$
- Treatment is available in 'Pre-metastatic Diagnosed'
  NOT in 'Pre-metastatic Unobserved' $\Rightarrow \mu_x^{13} < \mu_x^{23}$

# Multi-state model for BC transitions: semi-Markov model




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

# Modified Kolmogorov equations: semi-Markov model

$$\frac{d}{dt}\,{}_tp_x^{00} = -\,{}_tp_x^{00}\left(\mu_{x+t}^{01} + \mu_{x+t}^{02} + \mu_{x+t}^{04}\right)$$

$$\frac{d}{dt}\,{}_tp_x^{01} = {}_tp_x^{00}\,\mu_{x+t}^{01} - {}_tp_x^{01}\;\mu_{x+t}^{14} - \int_{u=0}^{t} {}_up_x^{00}\;\mu_{x+u}^{01}\;{}_{t-u}p_{[x+u]}^{11}\;\mu_{[x+u]+t-u}^{13}\;du$$

$$\frac{d}{dt}\,{}_tp_x^{02} = {}_tp_x^{00}\,\mu_{x+t}^{02} - {}_tp_x^{02}\,\mu_{x+t}^{24} - \int_{u=0}^{t} {}_up_x^{00}\;\mu_{x+u}^{02}\;{}_{t-u}p_{[x+u]}^{22}\;\mu_{[x+u]+t-u}^{23}\;du$$

$$\frac{d}{dt}\,{}_tp_x^{03} = \int_{u=0}^{t} {}_up_x^{00}\;\mu_{x+u}^{01}\;{}_{t-u}p_{[x+u]}^{11}\;\mu_{[x+u]+t-u}^{13}\;du + \int_{u=0}^{t} {}_up_x^{00}\;\mu_{x+u}^{02}\;{}_{t-u}p_{[x+u]}^{22}\;\mu_{[x+u]+t-u}^{23}\;du - {}_tp_x^{03}\left(\mu_{x+t}^{34} + \mu_{x+t}^{35}\right)$$

$$\frac{d}{dt}\,{}_tp_x^{04} = {}_tp_x^{00}\,\mu_{x+t}^{04} + {}_tp_x^{01}\,\mu_{x+t}^{14} + {}_tp_x^{02}\,\mu_{x+t}^{24} + {}_tp_x^{03}\,\mu_{x+t}^{34}$$

$$\frac{d}{dt}\,{}_tp_x^{05} = {}_tp_x^{03}\,\mu_{x+t}^{35}$$

- $\mu_{x,u}^{13} = \mu_{[x]+u}^{13}$ and $\mu_{x,u}^{23} = \mu_{[x]+u}^{23}$ with select attained age $[x]$ and duration $u$
- Differential equations involve integration over duration $u$

# A convenient parametrisation of the model

From

$$\mu_x^{01} + \mu_x^{02} = \mu_x^*$$

we can write

$$\mu_x^{01} = \alpha\, \mu_x^*$$
$$\mu_x^{02} = (1-\alpha)\, \mu_x^*, \qquad 0 < \alpha < 1$$

$\alpha$ : level of BC diagnoses

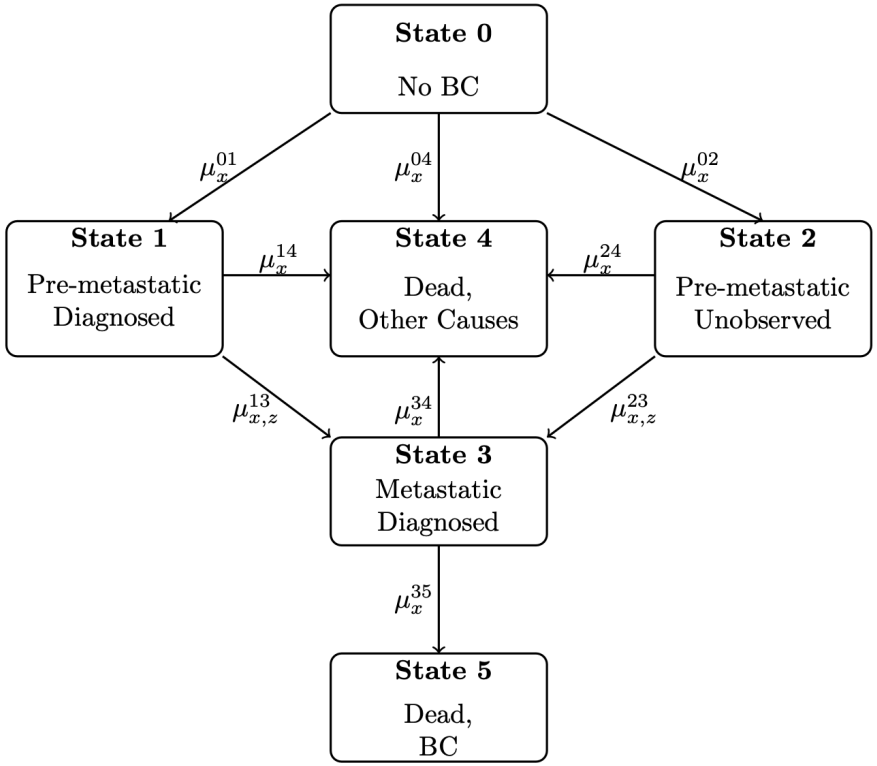
Also we assume

$$\mu_{x,z}^{13} = \beta\, \mu_{x,z}^{23}, \qquad \beta < 1$$

$\beta$ : availability of BC treatment

Transitions to death due to other causes from all 'live' states are equal to $\mu_x^{04}$

$$\mu_x^{14} = \mu_x^{24} = \mu_x^{34} = \mu_x^{04}$$

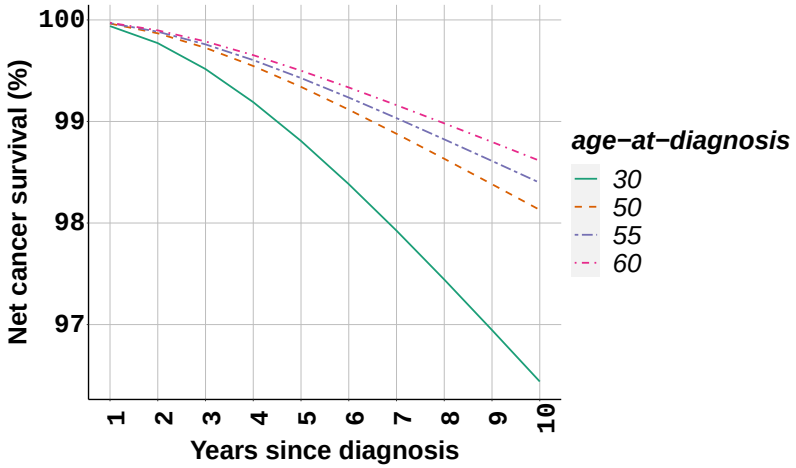


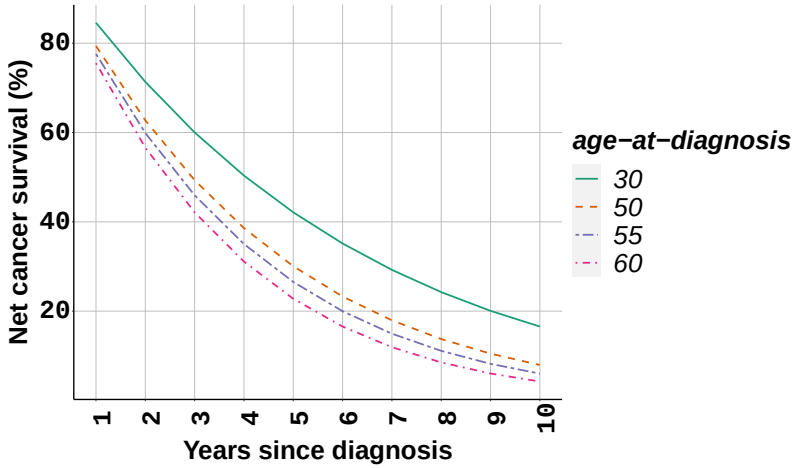
# BC model: pre-Covid rates

| Age | $\mu_x^{01}$ | $\mu_x^{04}$ | $\mu_x^{35}$ |
|---|---|---|---|
| 30–49 | 0.00086 | 0.00084 | 0.16739 |
| 50–54 | 0.00224 | 0.00228 | 0.24005 |
| 55–59 | 0.00233 | 0.00363 | 0.24005 |
| 60–64 | 0.00282 | 0.00588 | 0.28060 |
| 65–69 | 0.00318 | 0.00952 | 0.28060 |
| 70–74 | 0.00280 | 0.01643 | 0.36002 |
| 75–79 | 0.00311 | 0.02987 | 0.40000 |
| 80–84 | 0.00338 | 0.05496 | 0.49711 |
| 85–89 | 0.00362 | 0.10112 | 0.50000 |

- $\mu_x^{01}$ : ONS/NHS Digital data, 81% of new BC registrations, England, 2001–2019
- $\mu_x^{04}$ : ONS data, deaths from other causes, England, 2001–2019
- $\mu_{x,z}^{13}$ : Average metastasis rates per 1000 person-years;
  $\mu_x^{13} = 0.01954$ in the Markov model
  (Colzani et al., 2014)
- $\mu_x^{35}$ : BC deaths by age within 12 months after Stage 4 BC diagnosis (Zhao et al., 2020)

# BC net survival, semi-Markov model: pre-Covid rates




Pre-metastatic BC (left) v. Metastatic BC (right)

- Baseline scenarios are carried out for women when $\alpha = 0.6$ and $\beta = \frac{1}{7}$
- Net Survival: **ONLY** consider 'Dead, BC' as cause of death **AFTER** BC diagnosis
- An unusual age pattern in pre-metastatic BC net survival
- Lower metastatic BC net survival at older ages

For a woman aged $x$, diagnosed with pre-metastatic BC, BC survival in $t$ years:

$$\frac{1 - {}_tp_x^{14} - {}_tp_x^{15}}{1 - {}_tp_x^{14}}$$

# BC model - COVID scenario

**In order to** quantify the impact of COVID-19 on BC mortality at older ages, we have

- Excess deaths from other causes,
  i.e. increase in $\mu_x^{04}$
- Decline in BC diagnosis,
  i.e. slowdown in $\mu_x^{01}$ and increase in $\mu_x^{02}$

| Pandemic period | $\mu_x^{01}/\mu_x^{02}$ | $\mu_x^{04}$ | |
|---|---|---|---|
| | $\alpha$ | 65–84 | 85–89 |
| April–Nov. 2020 | 0.8 | 1.13 | 1.12 |
| Dec. 2020–Nov. 2021 | 1 | 1.13 | 1.12 |
| Dec. 2021–Dec. 2022 | 1 | 1.10 | 1.09 |
| Jan.–Dec. 2023 | 1 | 1.07 | 1.06 |
| Jan.–Dec. 2024 | 1 | 1.04 | 1.03 |

# Short-term implications up to 5 years

| Occupancy Probabilities (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | From State 0 | | | | | | | | | |
| Age | ${}_5p_x^{00}$ | ${}_5p_x^{01}$ | | ${}_5p_x^{02}$ | | ${}_5p_x^{03}$ | | ${}_5p_x^{04}$ | ${}_5p_x^{05}$ | |
| | M | M | S-M | M | S-M | M | S-M | M | M | S-M |
| Pre-pandemic calibration | | | | | | | | | | |
| 65–69 | 93.09 | 1.50 | *1.47* | 0.76 | *0.68* | 0.24 | *0.31* | 4.29 | 0.13 | *0.16* |
| 70–74 | 90.49 | 1.25 | *1.22* | 0.63 | *0.57* | 0.18 | *0.23* | 7.32 | 0.13 | *0.16* |
| 75–79 | 85.07 | 1.33 | *1.31* | 0.67 | *0.61* | 0.18 | *0.24* | 12.59 | 0.15 | *0.19* |
| 80–84 | 75.07 | 1.29 | *1.26* | 0.65 | *0.59* | 0.15 | *0.20* | 22.66 | 0.17 | *0.21* |
| 85–89 | 59.71 | 1.09 | *1.07* | 0.55 | *0.50* | 0.13 | *0.17* | 38.36 | 0.16 | *0.19* |
| Pandemic scenario | | | | | | | | | | |
| 65–69 | 92.73 | 1.45 | *1.42* | 0.78 | *0.70* | 0.24 | *0.32* | 4.66 | 0.14 | *0.17* |
| 70–74 | 89.90 | 1.20 | *1.18* | 0.65 | *0.58* | 0.18 | *0.24* | 7.93 | 0.14 | *0.17* |
| 75–79 | 84.09 | 1.28 | *1.25* | 0.69 | *0.62* | 0.18 | *0.24* | 13.60 | 0.16 | *0.20* |
| 80–84 | 73.42 | 1.22 | *1.20* | 0.66 | *0.59* | 0.16 | *0.21* | 24.36 | 0.18 | *0.22* |
| 85–89 | 57.53 | 1.02 | *1.00* | 0.55 | *0.49* | 0.13 | *0.17* | 40.61 | 0.16 | *0.20* |

- Semi-Markov (S-M) Model v. Markov (M) Model
- 3–6% decline in age-specific, ${}_5p_x^{01}$, 'Pre-metastatic Diagnosed'
- 3–5% increase in, ${}_5p_x^{03}$, 'Metastatic Diagnosed' (Vulnerability? Higher deaths from BC and other causes?)

# Changes in BC pre- v. post-pandemic

| | Excess deaths | | | | YLL | | | |
|---|---|---|---|---|---|---|---|---|
| Age | Dead (Other) | | Dead (BC) | | Dead (Other) | | Dead (BC) | |
| | State 4 | | State 5 | | State 4 | | State 5 | |
| | M | *S-M* | M | S-M | M | *S-M* | M | *S-M* |
| 65–69 | 363 | *363* | 8 | 10 | 7000 | *7010* | 152 | *193* |
| 70–74 | 607 | *607* | 7 | 9 | 9298 | *9293* | 113 | *138* |
| 75–79 | 1011 | *1012* | 8 | 10 | 11762 | *11770* | 92 | *116* |
| 80–84 | 1699 | *1699* | 7 | 9 | 14342 | *14340* | 63 | *76* |
| 85–89 | 2253 | *2253* | 5 | 6 | 13158 | *13158* | 29 | *35* |

- 100,000 women in each age group, in 'No BC' at time zero, taken as January 1, 2020
- 3–6% increase in 'Dead from BC' in the semi-Markov (S-M) model;

  5–8% increase in the Markov (M) model;

  5–8% increase in 'Dead from Other Causes' for women, with 'No BC' at time zero, across different ages over 5 years

Years of life expectancy lost (YLL) from a given cause is:

$$\text{YLL}_{x,t}^{\text{cause}} = D_{x,t}^{\text{cause}} e_x$$

where $D_{x,t}^{\text{cause}}$ is age- and type-specific additional deaths; and

$e_x$ is defined using standard life tables

# Summary (1)

- More equality in BC as compared to life-style cancers
- 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
- As compared to the pre-pandemic scenario
  - 3–6% increase in deaths from BC and 5–8% from other causes between ages 65–89
  - Less than a 1% change in the probability of death for women with pre-metastatic BC (${}_5p_x^{15}$)
  - A relatively significant change in the probability of death for women with metastatic BC (${}_5p_x^{35}$) as compared to women with pre-metastatic BC
- Measuring parameter and model uncertainty?

# Part 2: An application to life insurance products

A **considerable progress** in understanding BC due to

- medical research and data analysis

Better **options available** for people previously considered high-risk, e.g. women with breast cancer history

Examine existing models to see if they could lead to

- fairly priced, more inclusive coverage options

# Critical illness and life insurance products

We consider

- single benefit in an insurance contract:

  a specialised CII

  OR

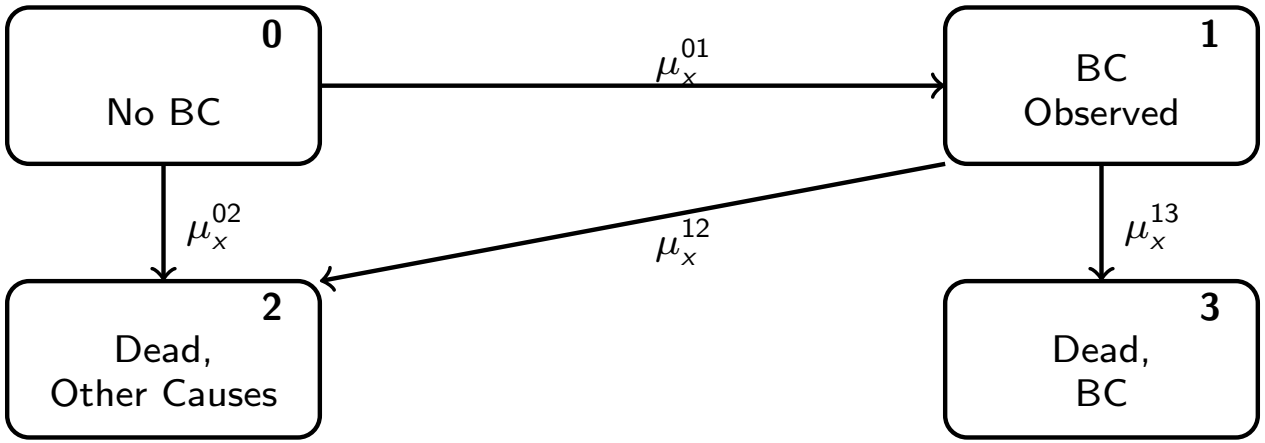
  a specialised life insurance (LI)

- benefit to be payable at the time of
  1. BC diagnosis or death from other causes in the CII contract
  2. death from any causes in the LI contract; and

- the LI contract can be purchased

  with pre-metastatic BC

# An industry-based Markov model




- A more compact version of the semi-Markov model
- Applied to CII by the insurance industry
  (Reynolds and Faye, 2016; Baione and Levantesi, 2018)
- **ONLY** account for observed BC cases
- Do not differentiate between different stages of BC

# All models: calibration

| Age | $\mu_x^{01}$ in M0 | $\mu_x^{01}$ in M1&M2 | $\mu_x^{02}$ in M0<br>$\mu_x^{04}$ in M1&M2 | $\mu_x^{13}$ in M0<br>$\mu_x^{35}$ in M1&M2 |
|---|---|---|---|---|
| 30–49 | 0.00106 | 0.00086 | 0.00084 | 0.16739 |
| 50–54 | 0.00277 | 0.00224 | 0.00228 | 0.24005 |
| 55–59 | 0.00287 | 0.00233 | 0.00363 | 0.24005 |
| 60–64 | 0.00349 | 0.00282 | 0.00588 | 0.28060 |
| 65–69 | 0.00393 | 0.00318 | 0.00952 | 0.28060 |
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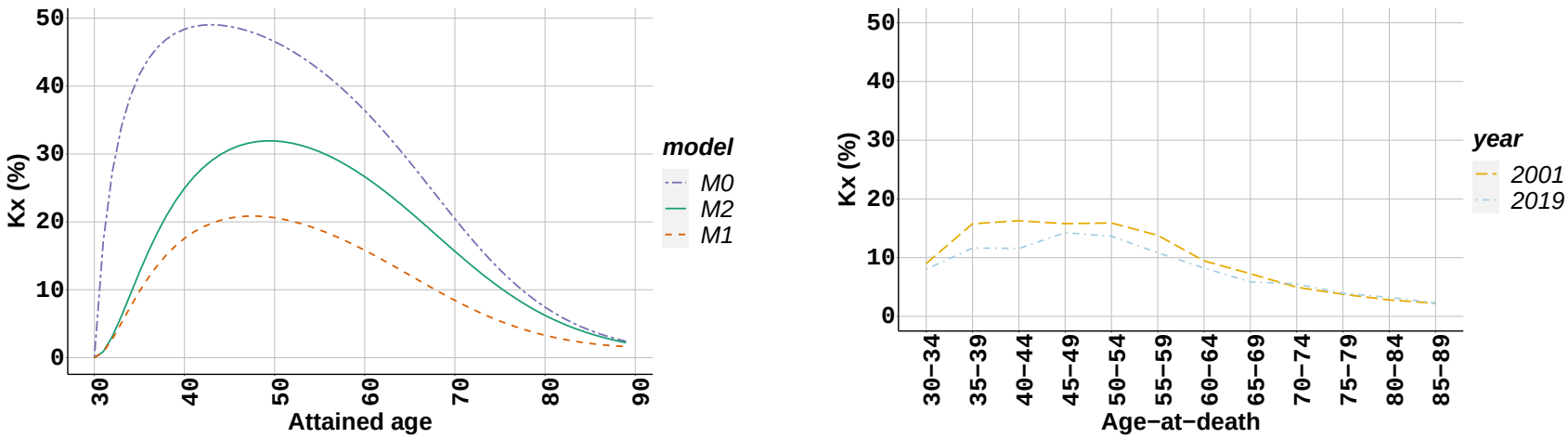
| 75–79 | 0.00384 | 0.00311 | 0.02987 | 0.40000 |
| 80–84 | 0.00417 | 0.00338 | 0.05496 | 0.49711 |
| 85–89 | 0.00447 | 0.00362 | 0.10112 | 0.50000 |

- Industry-based (M0) Model v. Semi-Markov (M1) Model v. Markov (M2) Model
- $\mu_x^{01}$ : ONS/NHS Digital data, 81% of new BC registrations in M1&M2, England, 2001–2019
- $\mu_x^{02}$ or $\mu_x^{04}$ : ONS data, deaths from other causes, England, 2001–2019
- $\mu_x^{13}$ or $\mu_x^{35}$ : BC deaths by age within 12 months after Stage 4 BC diagnosis (Zhao et al., 2020)

# An industry-based approach: $k_x$ method




Implied $k_x$ values (left) v. Observed $k_x$ values (right)

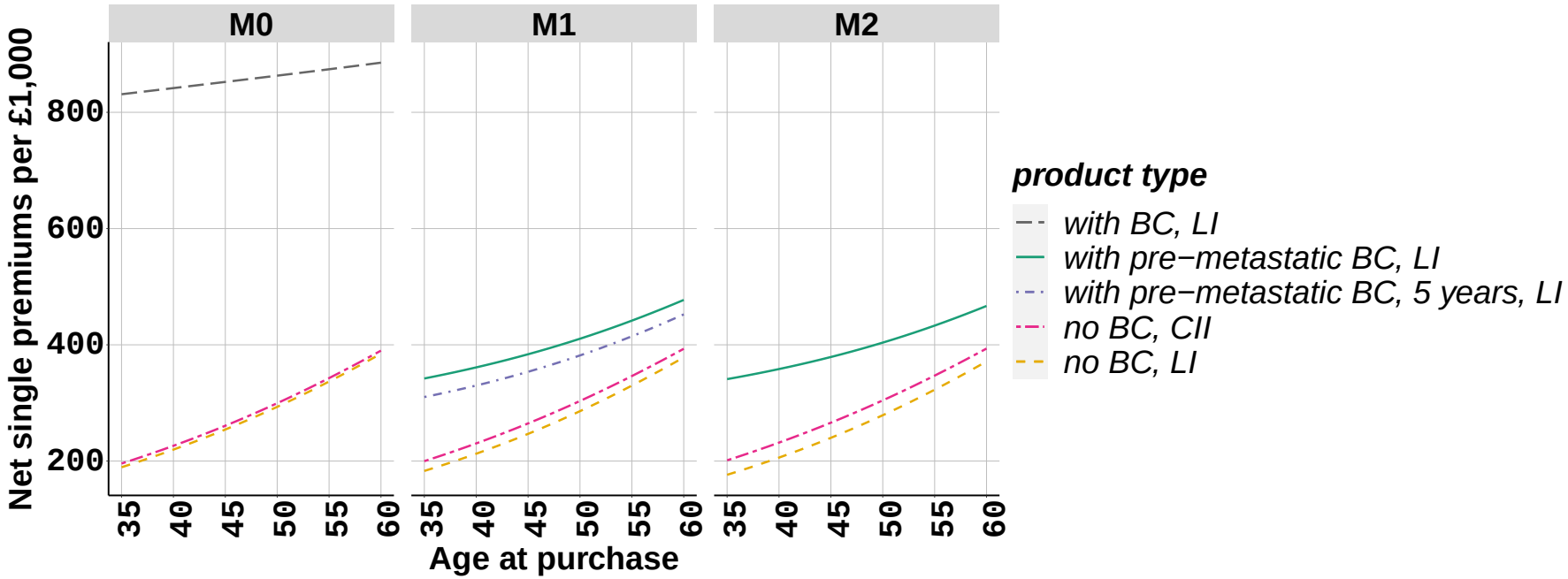
- Industry-based (M0) Model v. Semi-Markov (M1) Model v. Markov (M2) Model
- Difficulty in calibrating models, in the *absence of good quality cause of deaths data*, especially relevant in CII context
- $k_x$ method is to **indirectly** define deaths from other causes,

  accepting the proportion of CI causes to be $k_x$% of all deaths
- Significantly higher estimates under M0 (choice of $\mu_x^{13}$ ?)

The proportion of BC deaths, $k_x$ at attained age $x$, for instance, implied by M1 and M2

$$\hat{k}_x = \frac{{}_xp_0^{03}\mu_x^{35}}{{}_xp_0^{00}\mu_x^{04} + {}_xp_0^{01}\mu_x^{14} + {}_xp_0^{02}\mu_x^{24} + {}_xp_0^{03}\mu_x^{34} + {}_xp_0^{03}\mu_x^{35}}$$

# Net single premiums: whole life insurance




Whole life insurance contracts for $i = 4\%$

- Industry-based (M0) Model v. Semi-Markov (M1) Model v. Markov (M2) Model
- Premiums, no BC, CII (lowest under M0) > Premiums, no BC, LI
- Premiums, diagnosed with pre-metastatic BC at the time of purchase, LI > Premiums, no BC, LI
- Premiums, diagnosed with pre-metastatic BC at the time of purchase, LI > Premiums, diagnosed with pre-metastatic BC 5 years before purchase, LI (Impact of duration or time spent with pre-metastatic BC? Vulnerability?)

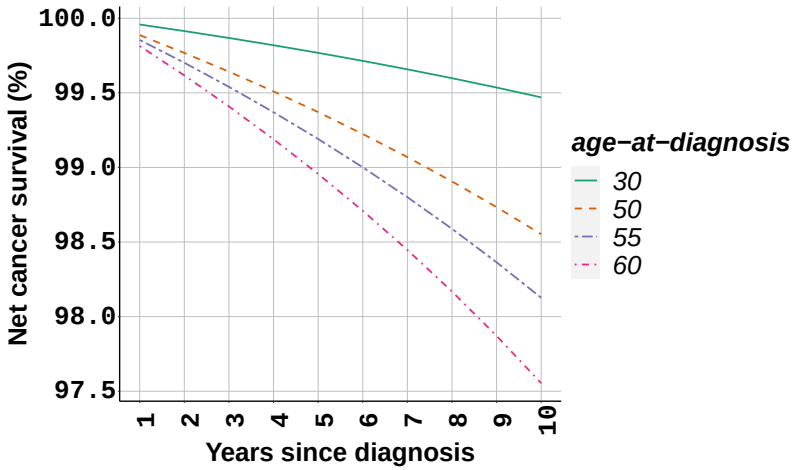
# What insights we gain from different models

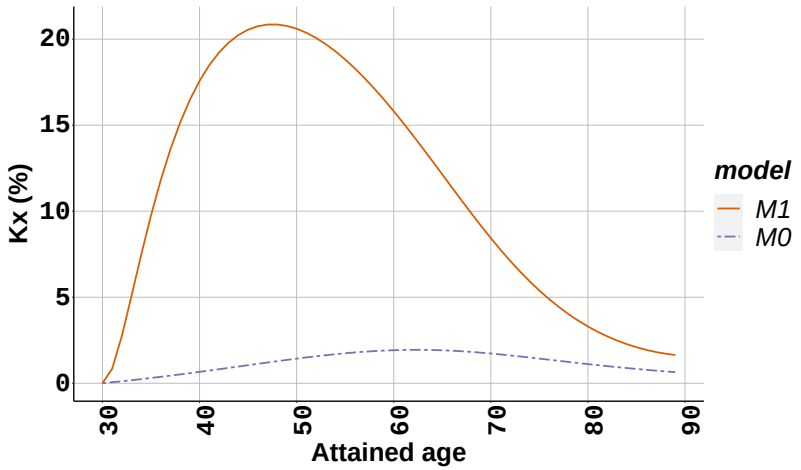
- **Lower CII premiums** under the industry-based model, **M0**, due to
  - number of departures from 'No BC'
  - definition of rates of transition $\mu_x^{01}$
  - absence of unobserved BC cases
- Duration dependence in the semi-Markov model, M1, enables
  - a more flexible and inclusive pricing methodology
  - results aligned with medical literature
- The risk of death from BC under M0 is considered to be high, linked to the risk of dying from metastatic BC
  - leading to very high LI prices for a woman with BC
  - suggesting sensitivity to this assumption

# Sensitivity analysis

- Sensitivity analysis is carried out, all else equal, with
  - $\alpha = 0.4$ and $\alpha = 0.8$ (lower v. higher BC diagnoses)
  - $\beta = \frac{1}{5}$ and $\beta = \frac{1}{10}$ (worse v. better BC treatment)
  - $\mu_x^{35}$ is 20% lower and higher than the pre-pandemic level (lower v. higher BC deaths)
  - $i$ =1–4% (lower v. higher interest rates)
- Consistent results in relation to relative changes in net single premiums under different parametrisation

# Impact of definition of BC deaths: M0




BC survival under M0 (left) v. Implied $k_x$ values (right)

- Industry-based (M0) Model v. Semi-Markov (M1) Model
- Baseline scenarios are carried out for women under M1 when $\alpha = 0.6$ and $\beta = \frac{1}{7}$
- The risk of death from BC under M0 is assumed to be similar to a woman with Stage 1 BC at the time of diagnosis
  - as opposed to be choosing this to be linked to Stage 4 BC
  - pointing sensitivity of M0
- The model is **NOT** capturing the age pattern in BC net survival as expected
- Very sensitive implied $k_x$ values under M0

# Summary (2)

- New medical technologies improve cancer survival
- Flexible models are relevant to medical underwriting of related insurance contracts
- Less than 1% change in net single premiums when key transition rates are defined including COVID years
- Duration dependence matters in actuarial applications
- Smaller differences across premiums under different models with an increasing age and a longer time to maturity
- Accounting for time trend in cancer incidence, type-specific mortality, and the risk of developing metastatic BC?

# More details in:


1. 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.

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, https://arxiv.org/abs/2303.16573.

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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