Insurance pricing for breast cancer under different multiple state models

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

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Outline

1. Motivation
2. Data
3. Multiple state models
4. Numerical illustration
5. Summary

Motivation

Cancer is

- a complex and heterogeneous pathology

A **considerable progress** in understanding this disease 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

Particular focus on:

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

Insurance prices providing coverage against cancer based on

1. an industry-based Markov model
2. a semi-Markov model
3. a special case of the semi-Markov model

Critical illness and life insurance products

We consider

- single benefit in an insurance contract:

  a specialised CII

  OR

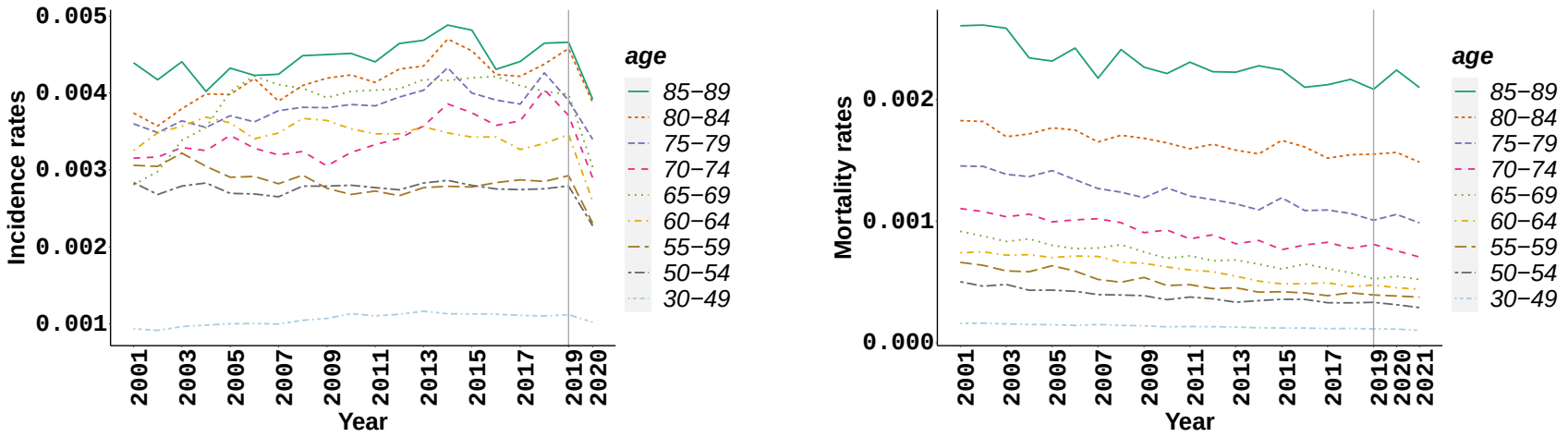
  a specialised life insurance (LI)

- 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

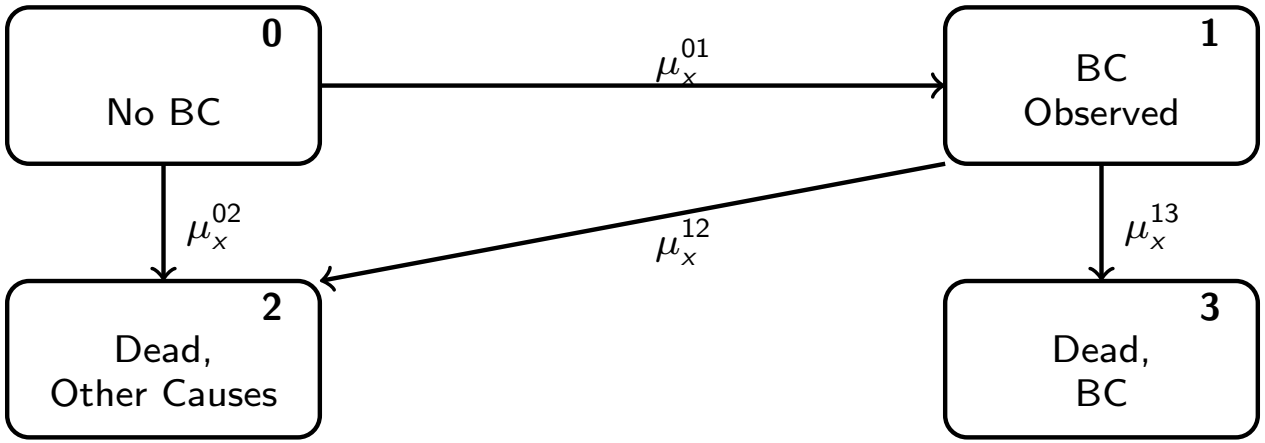
BC incidence and mortality in England



Incidence (left) v. Mortality (right)

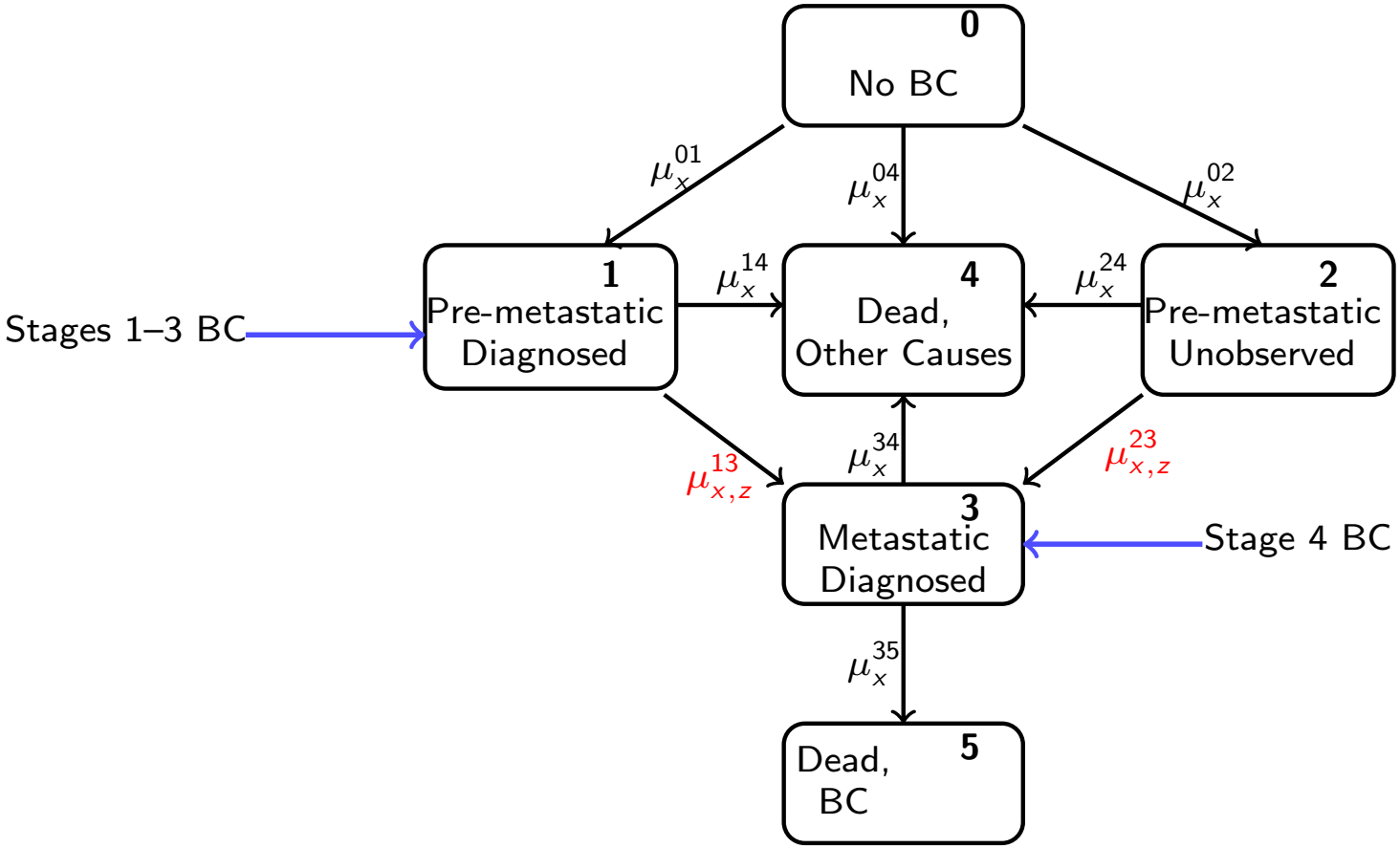
- A significant decline in BC incidence, as low as 25% at ages 60–64, in 2020 as compared to the same period in 2019
- An increase in BC mortality from ages 65+, as high as 7%, in 2020 as compared to the same period in 2019

An industry-based Markov model: M0



- 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

A semi-Markov model: M1



- 'Dead from BC' is only accessible from 'Metastatic Diagnosed'
- Onset of BC remains unchanged $\Rightarrow \mu_x^{01} + \mu_x^{02} = \mu_x^*$
- Duration dependence in 'Pre-metastatic Diagnosed' and 'Pre-metastatic Unobserved'
- No treatment in 'Pre-metastatic Unobserved' $\Rightarrow \mu_{x,z}^{13} < \mu_{x,z}^{23}$

A convenient parametrisation of M1

From

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

we can write

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

α : level of BC diagnoses

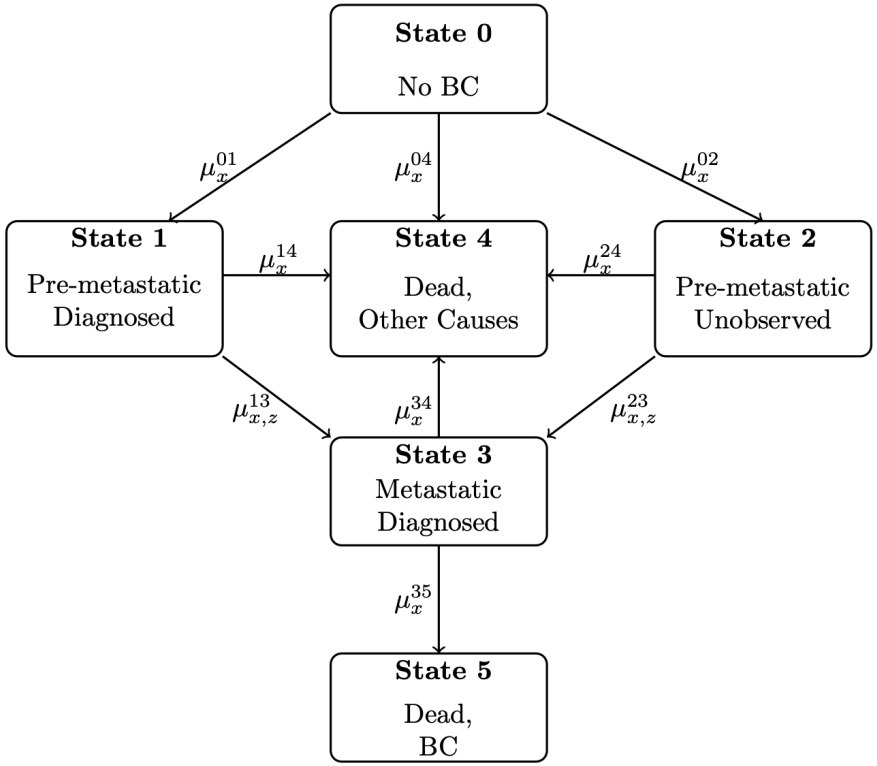
Also we assume

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

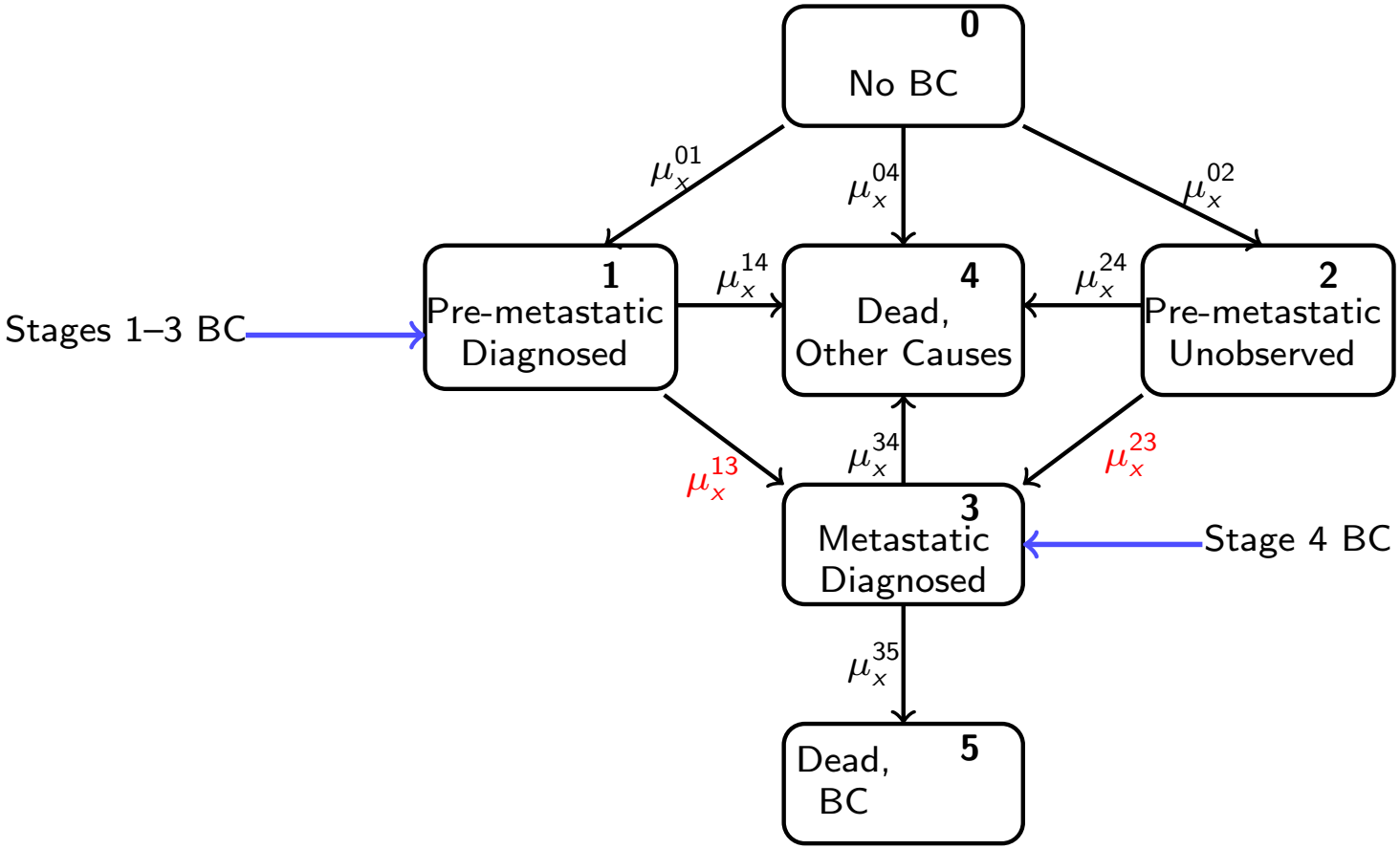
β : availability of BC treatment

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

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



A special case of the semi-Markov model: M2



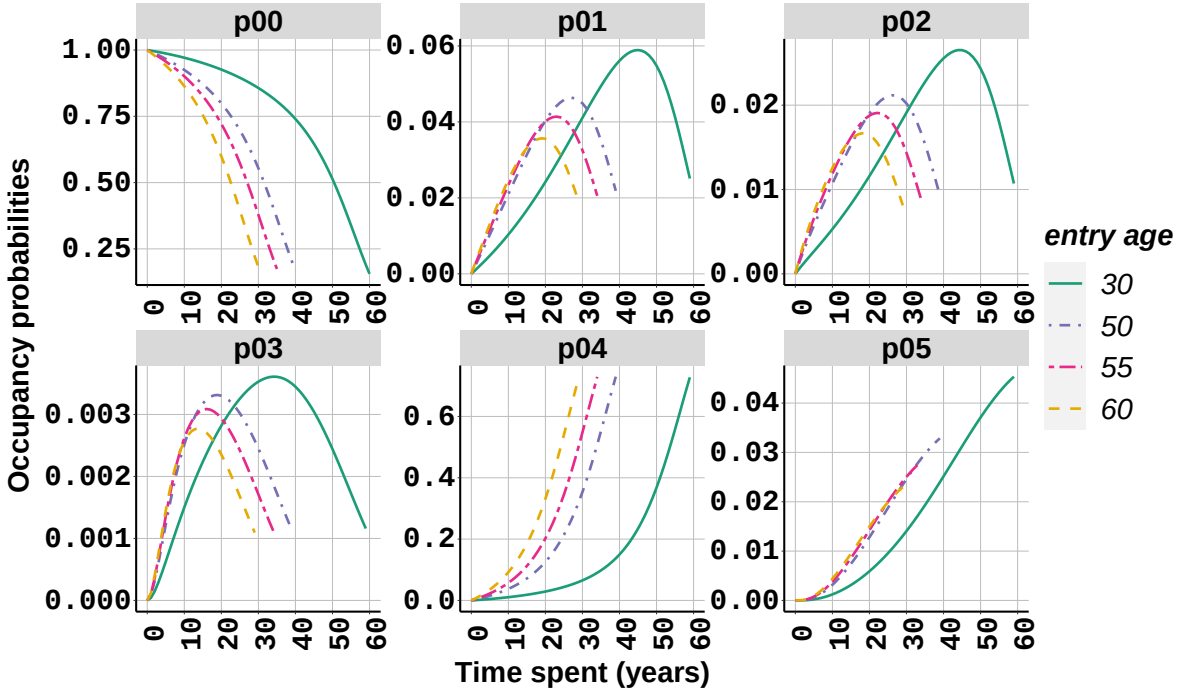
- NO duration dependence in 'Pre-metastatic Diagnosed' AND 'Pre-metastatic Unobserved'
- NO treatment in 'Pre-metastatic Unobserved' $\Rightarrow \mu_x^{13} < \mu_x^{23}$

All models: calibration

Age	μ_x^{01} in M0	μ_x^{01} in M1&M2	μ_x^{02} in M0 μ_x^{04} in M1&M2	μ_x^{13} in M0 μ_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
70–74	0.00345	0.00280	0.01643	0.36002
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

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

Occupancy probabilities: M1

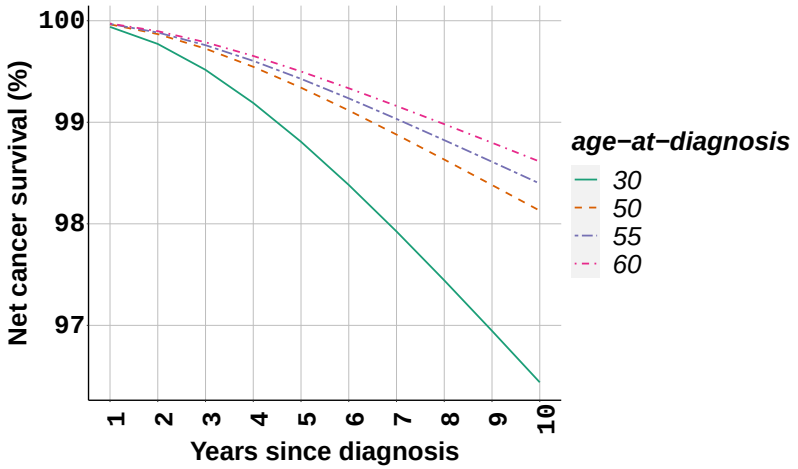


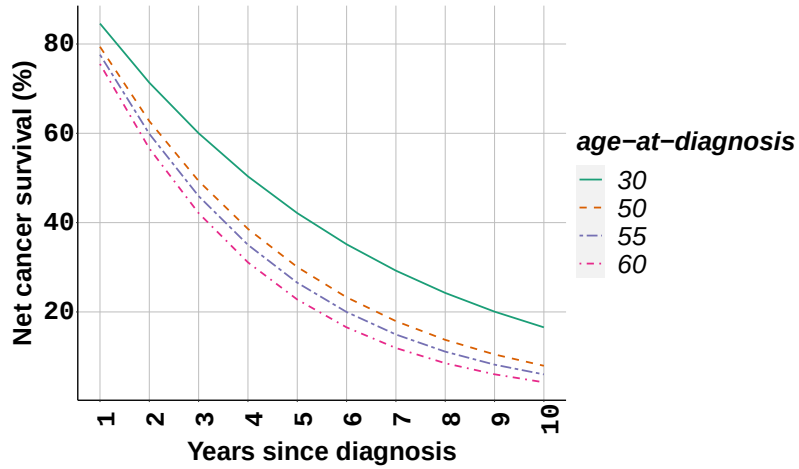
Generalised additive models to observed transition intensities, μ, in the form of:

$$g(E(\mu)) = \alpha + \sum_{p} s_p(x_p)$$

- α : intercept
- $g(.)$: a smooth monotonic link function
- μ : modelled as the sum of smooth functions, $s(.)$, of covariates x, i.e. attained age
- Maximum age is accepted to be 90, i.e. a policy is in force for at most 40 years for a 50 year old insured

Model validation: BC net survival





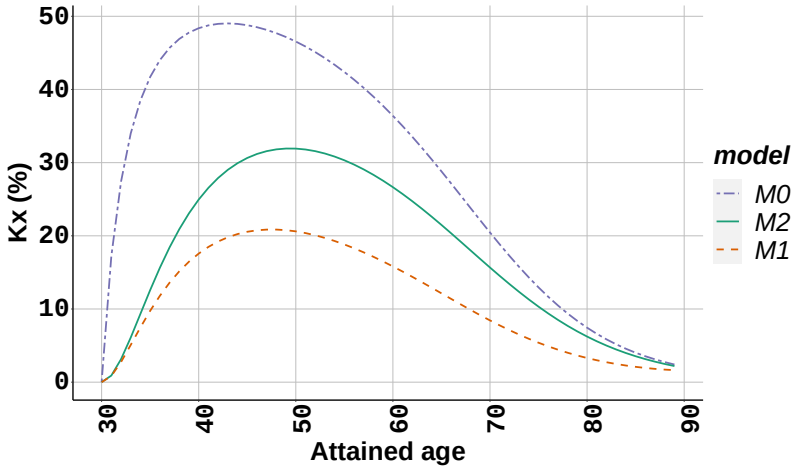
Pre-metastatic BC (left) v. Metastatic BC (right)

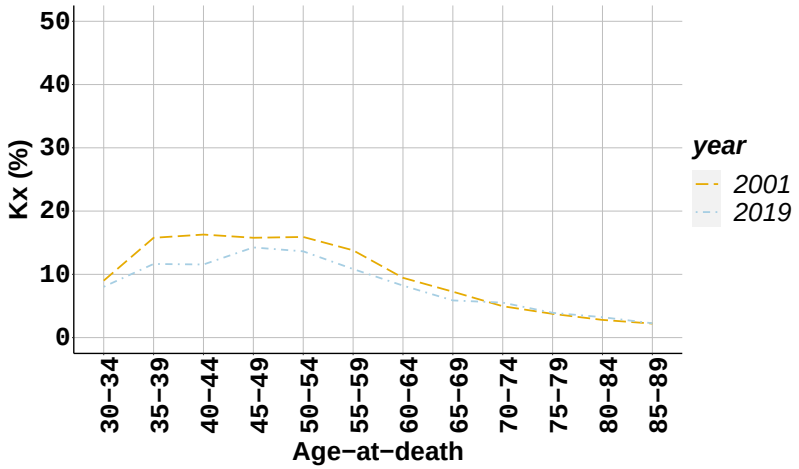
- Baseline scenarios are carried out for women when $\alpha = 0.6$ and $\beta = \frac{1}{7}$
- Net Survival: **ONLY** consider 'Dead, BC' as cause of death **AFTER** BC diagnosis
- An unusual age pattern in pre-metastatic BC net survival
- Lower metastatic BC net survival at older ages

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

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

An industry-based approach: k_x method





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

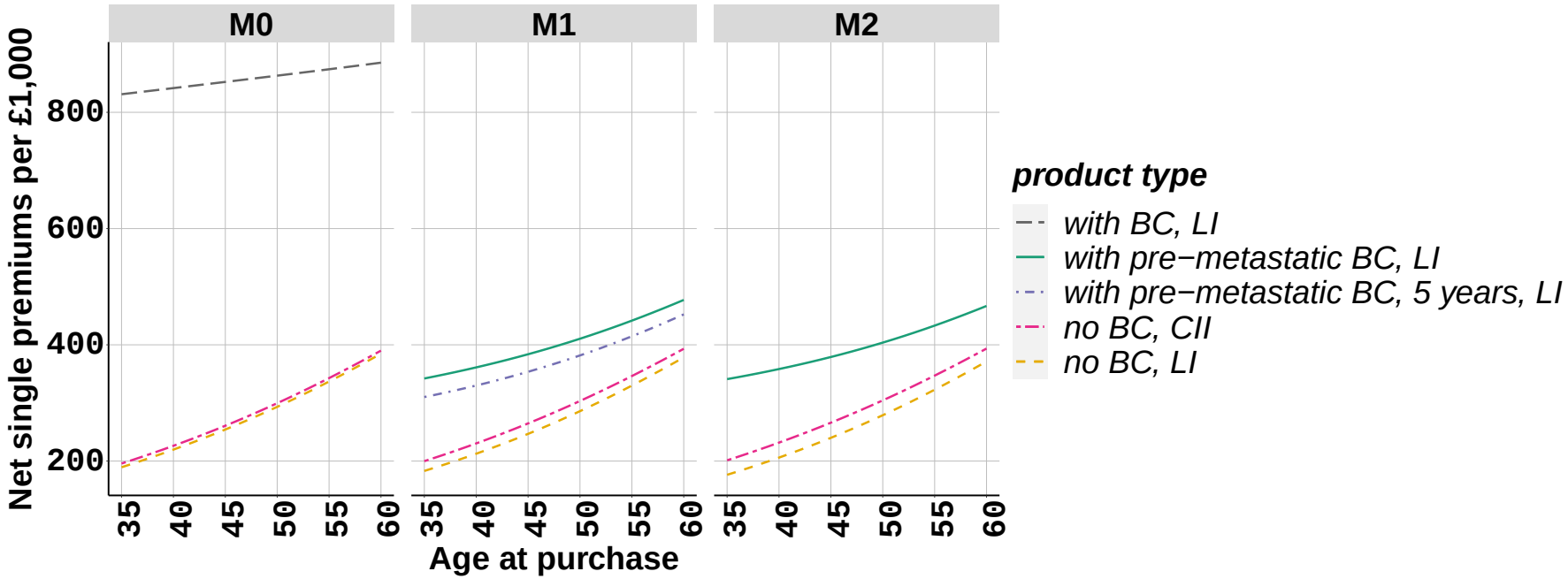
- Difficulty in calibrating models, in the *absence of good quality cause of deaths data*, especially relevant in CII context
- k_x method is to **indirectly** define deaths from other causes,

  accepting the proportion of CI causes to be k_x% of all deaths
- Significantly higher estimates under M0 (choice of μ_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 $i = 4\%$

- Premiums, no BC, CII $>$ Premiums, no BC, LI
- The lowest CII premiums under the industry-based model M0
- 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?)

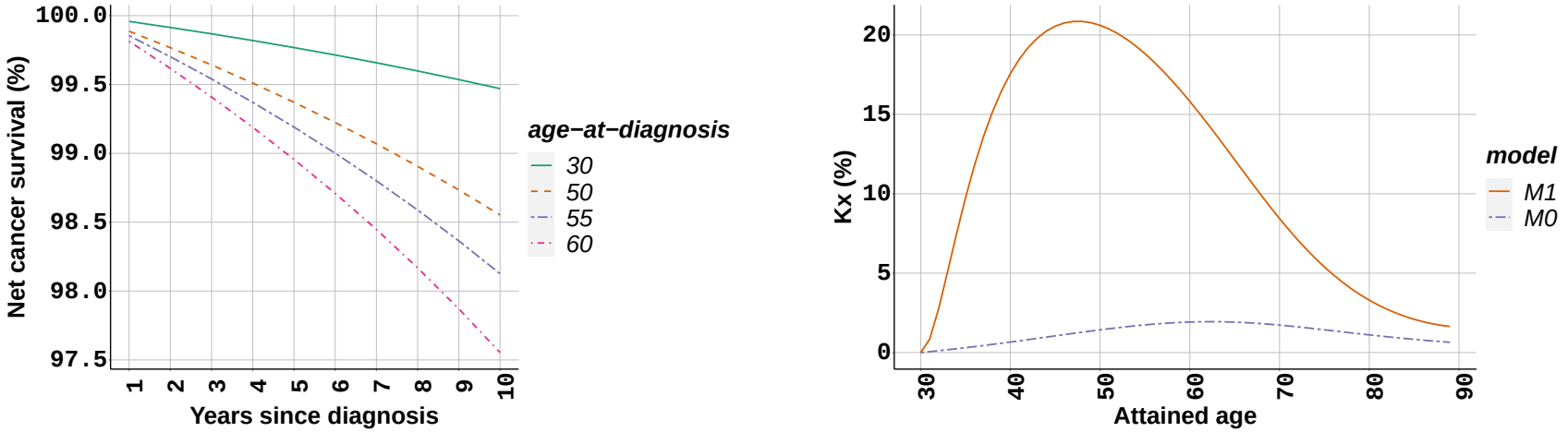
What insights we gain from different models

- **Lower CII premiums** under the industry-based model, **M0**, due to
  - number of departures from 'No BC'
  - definition of rates of transition μ_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)
  - μ_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)

- 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

- New medical technologies improve cancer survival
- Flexible models are relevant to medical underwriting of related insurance contracts
- 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
- Duration dependence matters in actuarial applications
- Smaller differences across premiums under different models with an increasing age and a longer time to maturity
- Measuring parameter and model uncertainty?
- 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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