YEARS OF LIFE LOST AND MULTISTATE MODELS FOR CANCER PATIENTS

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Introduction

Context

- **Mortgage loans** usually come with an insurance that pays the balance of the loan if the insured dies (*assurance solde restant dû*)
- Insurers often impose **surcharges** or refuse to cover the risk if the client has been diagnosed with cancer
- Lots of progress in medicine in the past decades
  - → prognosis of several cancer types improved
  - → establishment of **right to be forgotten** (= right not to declare a previous cancer if client survived *some* years after treatment's end)

Aims

- Estimate the **number of years of life lost** (YLL) due to cancer through the classical survival curves and a **multistate model** (MSM)
- Make the link between the two, which is rarely done in the literature

- Work in progress:
  - Use the 2 concepts to show how they can be used to re-think the **access of cancer patients to insurance products**, with a focus on financial contracts with finite horizon:
    - **loan**: small YLL $\Rightarrow$ limited losses for insurers and market can absorb the extra mortality due to cancer
    - **life annuity**: due to their reduced lifetime, cancer patients may be eligible for reduced premiums when buying insurance products including benefits in case of survival
  - Apply it to other financial products thanks to its flexibility

Data

Cancer patients and general population

- Data from the Belgian Cancer Registry (BCR)
- **Melanoma, thyroid and female breast cancers** as illustrations (many cases before the age of 40 and relatively high survival rate)
- 140,241 cases in total
- Diagnosed between 2004 and 2018, follow-up until 2020
- Belgian population life tables obtained from Statbel for mortality in the general population

Methods

Methods

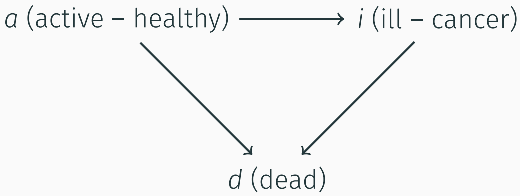
- YLL quantifies the number of **years of life** a cohort of patients has **lost due to a given disease** (cancer in our case) compared to the general population
  - → "How many years of life a patient is expected to lose due to his/her cancer?"
- Measured on a **time metric** (= easy to interpret) and **cause of death** is **not needed** (making it practical for population-based studies)
- Estimated as the difference between the area under the survival curves of the general population and the cohort of interest:

$$YLL_C(\tau) = \int_0^\tau S_P(t)dt - \int_0^\tau S_C(t)dt, \quad (1)$$

(up to time τ because our focus is on contracts with finite horizon)

Methods

- Classical **survival analysis = 2-state model** with an initial state (“healthy” or “active”) and a final state (“dead”)
- MSM can be seen as an extension; they are used to study the **evolution of individuals** between **more than 2 states**:



Methods

- Information for a MSM is typically summarized via the **transition intensities**, which quantifies the **instantaneous risk of making a given transition** depending on the state currently occupied:

$$\mu_{x+t}^{ai} = \lim_{h \to 0} \frac{{}_h p_{x+t}^{ai}}{h}$$

$$\mu_{x+t}^{ad} = \lim_{h \to 0} \frac{{}_h p_{x+t}^{ad}}{h}$$

$$\mu_{x+t;z}^{id} = \lim_{h \to 0} \frac{{}_h p_{x+t;z}^{id}}{h}, z < t$$

Methods

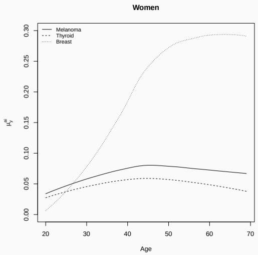


Figure 1: μ^{ai} for women

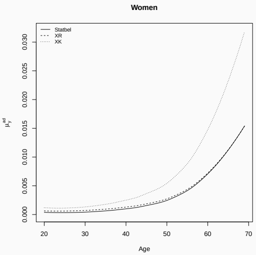


Figure 2: μ^{ad} for women

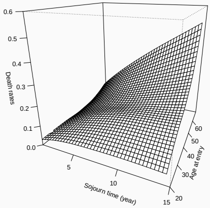
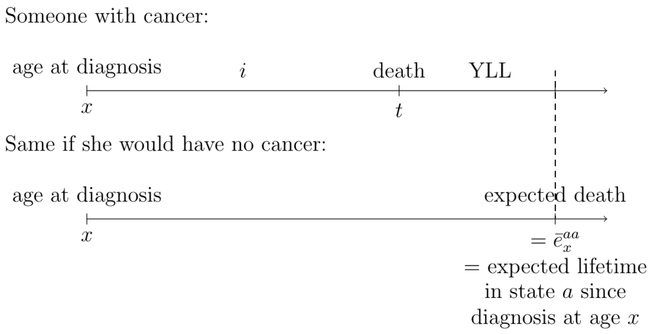


Figure 3: μ^{id} for men with melanoma cancer

Methods

- The first contribution is that we estimate **YLL from a 3-state MSM**:



We have thus

$$YLL = \bar{e}_x^{aa} - t$$

- Another contribution is to illustrate how they can adapt to different financial products by adding different weights (*in development*)

Results

Results

Gender	Cancer site	Age	$\widehat{\text{YLL}}_C^{SC}$ ($CI_{95\%}$)	$\widehat{\text{YLL}}_C^{MSM}$ ($CI_{95\%}$)
Men	Melanoma	20-34	1.24 (0.93; 1.55)	1.12 (0.93; 1.31)
		35-49	1.47 (1.26; 1.68)	1.20 (0.92; 1.48)
		50-69	1.74 (1.53; 1.95)	1.52 (1.31; 1.73)
	Thyroid	20-34	0.16 (0.00; 0.40)	0.17 (0.02; 0.32)
		35-49	0.61 (0.31; 0.91)	0.97 (0.93; 1.01)
		50-69	1.32 (0.94; 1.70)	1.89 (1.84; 1.94)
Women	Melanoma	20-34	0.40 (0.28; 0.51)	0.89 (0.82; 0.96)
		35-49	0.66 (0.55; 0.77)	0.44 (0.00; 0.88)
		50-69	0.98 (0.83; 1.13)	1.60 (1.46; 1.74)
	Thyroid	20-34	**0.05** (0.00; 0.13)	0.09 (0.08; 0.10)
		35-49	0.14 (0.04; 0.24)	0.21 (0.97; 1.07)
		50-69	0.69 (0.50; 0.88)	0.97 (0.86; 1.08)
	Breast	20-34	**2.17** (1.95; 2.40)	1.95 (1.92; 1.98)
		35-49	1.34 (1.28; 1.40)	0.93 (0.53; 1.33)
		50-69	1.48 (1.43; 1.53)	0.90 (0.67; 1.13)

Table 1: Number of life years lost due to cancer over a 15-year time window, estimated via survival curves; $\widehat{\text{YLL}}_C^{SC}$, and via MSM; $\widehat{\text{YLL}}_C^{MSM}$

Results

- It is known that **mortality risks** associated with cancer **decrease with time** since diagnosis
- We also evaluate the impact of adding a **waiting period**, which can be linked to the length of the right to be forgotten

$$
\begin{aligned}
YLL_C^W &= YLL_C(\tau) - YLL_C(i) \\
&= \int_0^\tau S_P(t)dt - \int_0^\tau S_C(t)dt - \left[\int_0^i S_P(t)dt - \int_0^i S_C(t)dt\right] \\
&= \int_i^\tau S_P(t)dt - \int_i^\tau S_C(t)dt \qquad \forall i = 0, 1, \ldots, 15
\end{aligned}
\tag{2}
$$

Results

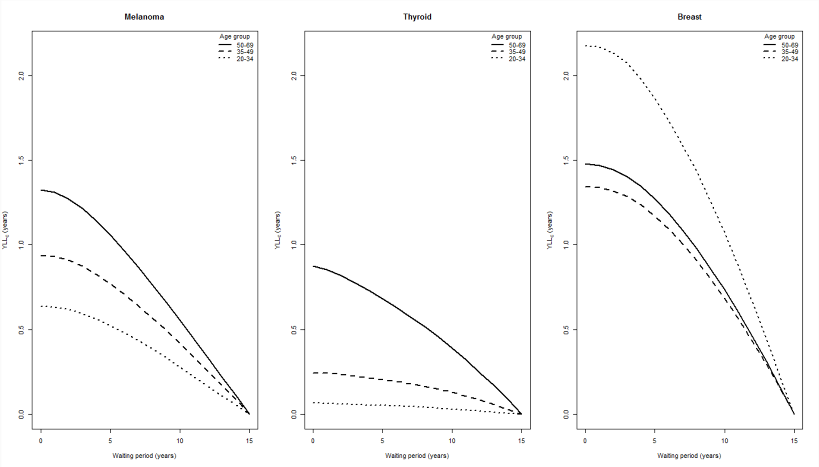


Figure 4: Estimated number of years of life lost due to cancer ($\widehat{YLL_C^W}$) over a 15-year time window, with the inclusion of a waiting period of 0 to 15 years.

Future research

Future research

Next steps?

1. Apply the methodology to other financial products
2. Modelling complex non-linear relationships thanks to **splines regression**
   - Adaptive splines (A-splines) with automatic knots selection (Goepp et al., 2018)

Thank you!

Questions?