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Assumptions on mortality

Future mortality in selected European countries, taking into account the impact of lifestyle epidemics

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Summary

Estimates of future mortality often prove inaccurate, as conventional mortality projection methods do not capture (i) the impact of lifestyle 'epidemics', different over time between men and women, and across generations and countries; and (ii) the mortality experience of other countries.

We coherently projected mortality in selected European countries taking into account the impact of the smoking, obesity and alcohol 'epidemics'.

We used age-, sex-, year- and country-specific (i) all-cause mortality data from the Human Mortality Database, (ii) lung cancer mortality data from WHO to indirectly estimate smoking-attributable mortality, (iii) alcohol-attributable mortality data from the Global Burden of Disease Study (ages 20-64) supplemented with WHO cause-specific mortality data, and (iv) obesity prevalence data from the NCD Risk Factor Collaboration study to estimate obesity-attributable mortality.

We projected smoking, alcohol and obesity-attributable mortality fractions by novel projection methodologies that account for the wave pattern of lifestyle 'epidemics', and combined these into future lifestyle-attributable mortality fractions (LAMF) using a multiplicative approach. Future LAMF estimates are combined with Li-Lee coherent projections of non-lifestyle-attributable mortality. Our projections of life expectancy at birth (e0) up to 2065 are compared with direct individual and coherent all-cause mortality projections.

The past increase in e0 (1990-2014) is less strong for non-lifestyle-attributable mortality compared to all-cause mortality among men, but slightly stronger among women. LAMF is projected to further decline among men and to first increase and then decline among women. When we integrate lifestyle epidemics in individual projections, future e0 (eventually) moves back to e0 for non-lifestyle-attributable mortality. Including lifestyle epidemics when coherently forecasting mortality results in higher e0 levels and more convergence between men and women.

Mortality projections that take into account likely future changes in smoking, alcohol and obesity, thus, result in higher future e0 and - when projecting coherently - in larger convergence between the sexes.

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I.   INTRODUCTION

1. Smoking, excessive alcohol consumption, and overweight and obesity are respectively the first, third and fourth most significant preventable risk factors in the European Union (WHO 2009). These lifestyle factors are important determinants of mortality differences between sexes and countries (Janssen et al. 2007; Trias-Llimós et al. 2018; GBD 2015 Obesity Collaborators 2017). More importantly, however, these lifestyle factors have a clear impact on trends in overall mortality, because their prevalence and attributable mortality generally evolve as wave-shaped lifestyle 'epidemics' with an initial unprecedented increase across many countries, followed (eventually) by declines.

2. The *smoking epidemic* displays the strongest wave pattern, observed for smoking-attributable mortality about 30 years later than for smoking prevalence (Lopez et al. 1994). The effects on mortality trends are large, particularly among men in Anglosaxon countries and northwestern Europe (Stoeldraijer et al. 2015; Janssen 2019). *Obesity* prevalence has tripled in Europe since 1980 (WHO Regional Office for Europe 2007), reflecting the early stages of the obesity epidemic (Xu & Lam 2018). While the impact of obesity on life expectancy in Europe is smaller than that of smoking, it has been increasing over time (Vidra et al. 2019). There are signs that the obesity epidemic is recently levelling off (Rokholm et al. 2010). *Excessive alcohol consumption* is especially prevalent among men in eastern Europe, resulting in highly fluctuating patterns and substantial alcohol-related mortality (Rehm et al. 2009; Trias-Llimós et al. 2018). In many North-western European countries, alcohol-attributable mortality has, since 1990, first increased and then declined or stagnated (Trias-Llimós 2018).

3. In the evolvement of these epidemics and in smoking-, alcohol- and obesity-attributable mortality also the birth cohort dimension has been found to be important (e.g. Janssen & Kunst 2005; Trias-Llimos et al. 2017; Vidra et al. 2018). Such a birth cohort dimension stems from the joint uptake of lifestyle behaviours among people born in the same year, and/or going through adolescence together.

4. These important (expected) changes over time and over successive cohorts/generations in smoking- , obesity- and alcohol-attributable mortality are important to take into account when forecasting mortality (e.g. Olshansky et al. 2009; French & O'Hare 2013; Janssen et al. 2013; Bongaarts 2014; Janssen 2018; Foreman et al. 2018).

5. That is, projection of mortality is still mostly done by means of extrapolating past trends over time in (logged) age-specific mortality, thereby mostly making use as well of regularities in the age pattern (Booth and Tickle 2008; Stoeldraijer et al. 2013a). When past trends in mortality are non-linear because of the effect of lifestyle factors (for example in Denmark, the Netherlands, and United Kingdom as a result of the smoking epidemic), the outcomes will become dependent on the historical period chosen for the extrapolation (Janssen et al. 2013; Stoeldraijer 2019) leading to non-robust outcomes. Also, giving the importance of lifestyle factors, a mere extrapolation of past trends will lead to inaccurate estimates, as it ignores the non-linearity and the cohort dimension of lifestyle-attributable mortality. In addition, given important differences between countries in the timing of the non-linear lifestyle-epidemics (Janssen 2019; Trias-Llimós 2018; Vidra 2019), the idea of coherent mortality projections (in which the mortality experience of other related countries is taking into account)(e.g. Li & Lee 2005) applies especially to non-lifestyle-attributable mortality and not necessarily to all-cause mortality.

6. Objective of the Future Mortality project is to project all-cause mortality in Europe taking into account the impact of the smoking, obesity and alcohol 'epidemics', and the mortality experience in other countries. See www.futuremortality.com for more information. In the current working paper I will present the preliminary results for six European countries: Belgium, France, Spain, Finland, Poland, Hungary

II.   DATA AND METHODS

7. All-cause mortality and exposure data (1950-2016) by singly year of age, sex, country, and year is obtained from the Human Mortality Database (HMD 2019). Smoking-attributable mortality fractions (1950-2014; 35-100) are indirectly estimated (Peto et al. 1992; Janssen 2019) using lung cancer mortality data from the WHO Mortality Database (WHO 2018). Alcohol-attributable mortality fractions (1990-2016; 20-100) are calculated based on alcohol-attributable mortality rates obtained from the Global Burden of Disease Study 2017 (Stanaway et al. 2018; GBD Collaborative Network 2018) thereby implementing a different age pattern from ages 65 and over, using mortality from alcohol-related causes of death from WHO (ICD10 codes: (F10, K70, X45, G312, G621, G721, I426, K292, K860, Q860, X65 and Y15) (WHO 2018). Obesity-attributable mortality fractions (1975-2016; 20-100) are estimated by applying the population-attributable fraction formula to obesity prevalence data from the NCD Risk Factor Collaboration study 2017 (Abarca-Gómez et al. 2017) and relative risks of dying from obesity from a meta-review (DYNAMO-HIA Consortium 2010). The data is by five-year age groups, sex, country and year. We used Loess smoothing to convert estimates by five year age groups into estimates by single year of age. See here for more information on the data sources and on the estimation of lifestyle-attributable mortality. We combined the smoking-, alcohol- and obesity-attributable mortality fractions into lifestyle-attributable mortality fractions (LAMF) using the multiplicative approach (Ezzati et al. 2003), to account for the overlap between the effects of the three lifestyle factors. This generated estimates of LAMF from 1990 onwards, for ages 20-100.

8. Our indirect projection of all-cause mortality entails the combination of the separate projection of lifestyle-attributable mortality and the coherent projection of non-lifestyle-attributable mortality, in line with the approach by Janssen et al (2013) who included the smoking epidemic in coherent projections for the Netherlands. We projected e0 up to 2065 for each country by sex.

9. Firstly, we projected smoking, alcohol and obesity-attributable mortality fractions up to age 84 separately by means of novel projection methodologies that include the wave pattern of lifestyle 'epidemics' and/or the importance of the cohort dimension. Obesity prevalence is projected by applying the age-period Lee-Carter model to the transformed logit of prevalence over the period 1975-2016, and by linearly extrapolating the trend in the first order difference (velocity) from 2000 onwards (from 1985 onwards for Eastern European women). Smoking-attributable and alcohol-attributable mortality are analyzed by applying age-period-cohort modelling (following the approach by Cairns et al. 2009)) to the respective transformed fractions (1950 onwards for smoking, 1990 onwards for alcohol) using a generalized logit link function. Subsequently the period parameter is forecasted by means of a quadratic curve, or – when already declining for a long time (for smoking-attributable mortality among men, and for alcohol-attributable mortality in a number of countries) by means of extrapolating this decline. The cohort parameter is projected by extrapolating the most recent trend, after burning some outer cohorts. In performing these lifestyle-specific projections we ensured, by the implementation of upper and lower bounds, that the projections would not lead to (i) unlikely crossovers between countries and both sexes and (ii) unlikely zero future prevalence or mortality fraction levels. See here for more information on the projection of smoking, obesity, and alcohol-attributable mortality. We extended the projections of obesity-, smoking- and alcohol-attributable mortality up to age 100, by linearly extrapolating the logit of the fractions/prevalence for ages 75-84. We, subsequently, combined the projections of obesity-, smoking- and alcohol-attributable mortality to projected lifestyle-attributable mortality fractions (LAMF)(20-84) using, again, the multiplicative approach (Ezzati et al. 2003).

10. Secondly, we coherently projected non-lifestyle-attributable mortality fractions (1 – LAMF) up to age 100 by the often used Li & Lee projection methodology (Li & Lee 2005; Stoeldraijer 2019), which applies the Lee-Carter methodology twice: first to the populations that together form the common trend and second to the country-specific residuals from the first round. The common (Bx Kt) and country-specific parameters (a(x,i), k(t,i) and b(x,i)) together result in the augmented common factor model. We estimate the comon parameters by applying Lee-Carter model in the weighted average mortality rates of France, Spain and Italy, given that these European populations experienced a very strong linear increase in life expectancy in the past (Stoeldraijer 2019). The past trend in the common time trend Kt is extrapolated using the ARIMA(0,1,1) model with drift,

which provided the best fit (= minimum AICc). For the population-specific trend kti we used a random walk with no drift and so assumed non-stationarity. We generated the parameter estimates based on Poisson-likelihood (Brouhns et al. 2002; Renshaw & Haberman 2006)
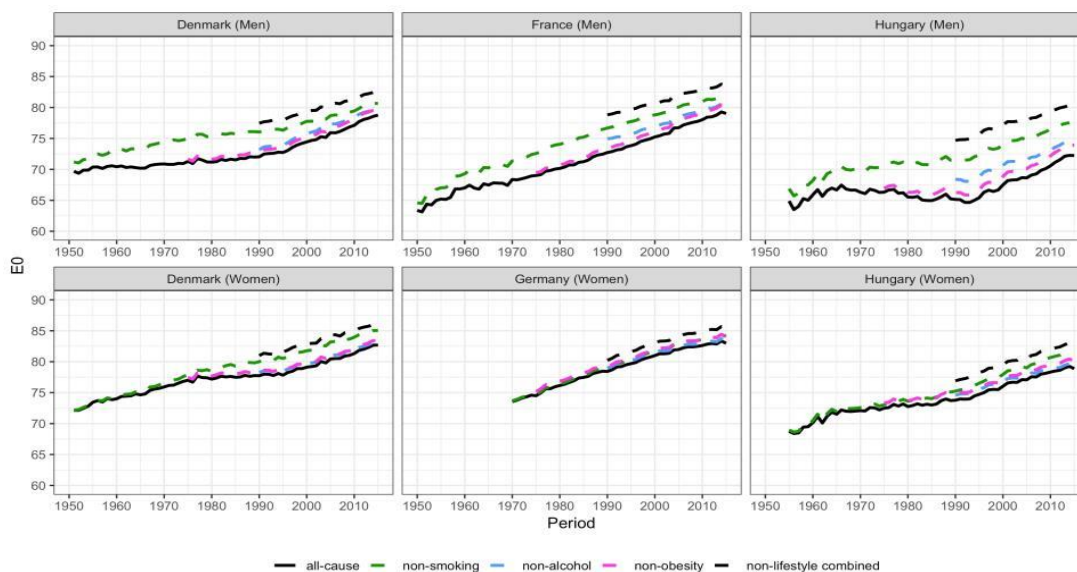
Thirdly, we combined the projection of lifestyle-attributable mortality with the coherent projection of non-lifestyle-attributable mortality by: $m(x,t)^{allcause} = m(x,t)^{non-lifestyle} \cdot \left(\frac{1}{1-LAMF(x,t)}\right)$ (Janssen et al. 2013). We estimate mortality rates for ages 101-130 by applying the Kannisto model of old-age mortality (Thatcher et al. 1998) to mortality for ages 80 and over.

11. We compared the coherent projections of life expectancy at birth (e0) up to 2065 taking into account the lifestyle epidemics (indirect coherent) with (i) individual projections taking into account lifestyle (indirect individual), (ii) individual projections of all-cause mortality (direct individual), and (iii) coherent projections of all-cause mortality (direct coherent). For the projection of the period parameter in the Lee-Carter model we applied the common assumption of a random walk with drift (Lee & Carter 1992; Renshaw & Haberman 2006) and again apply a Poisson-likelihood maximization process.

III. RESULTS

12. Figure 1 compares trends in life expectancy at birth (e0) for all-cause mortality with trends in e0 for non-lifestyle-attributable mortality, from 1950-2016 for six selected European populations. Whereas for all-cause mortality we see stagnations in the increase (men, Danish women), the increase in e0 for non-smoking-attributable mortality is more gradual. Examining more closely the period from 1990 onwards, for which information on all three lifestyle factors are available, we can observe that for men the e0 for non-lifestyle-related mortality is increasing less strong over the period 1990-2014 as compared to the e0 for all-cause mortality. This is mostly because the decline in smoking-related mortality among men is positively influencing the increase in e0 for all-cause mortality. For women, however the increase in e0 for non-lifestyle-related mortality is slightly higher compared to the increase in e0 for all-cause mortality. This is because especially smoking and – to a lesser extent - obesity has a negative effect on the trend in all-cause mortality. Differences between e0 for all-cause mortality and e0 for non-lifestyle-attributable mortality are larger for men compared to women, because of higher lifestyle-attributable mortality.
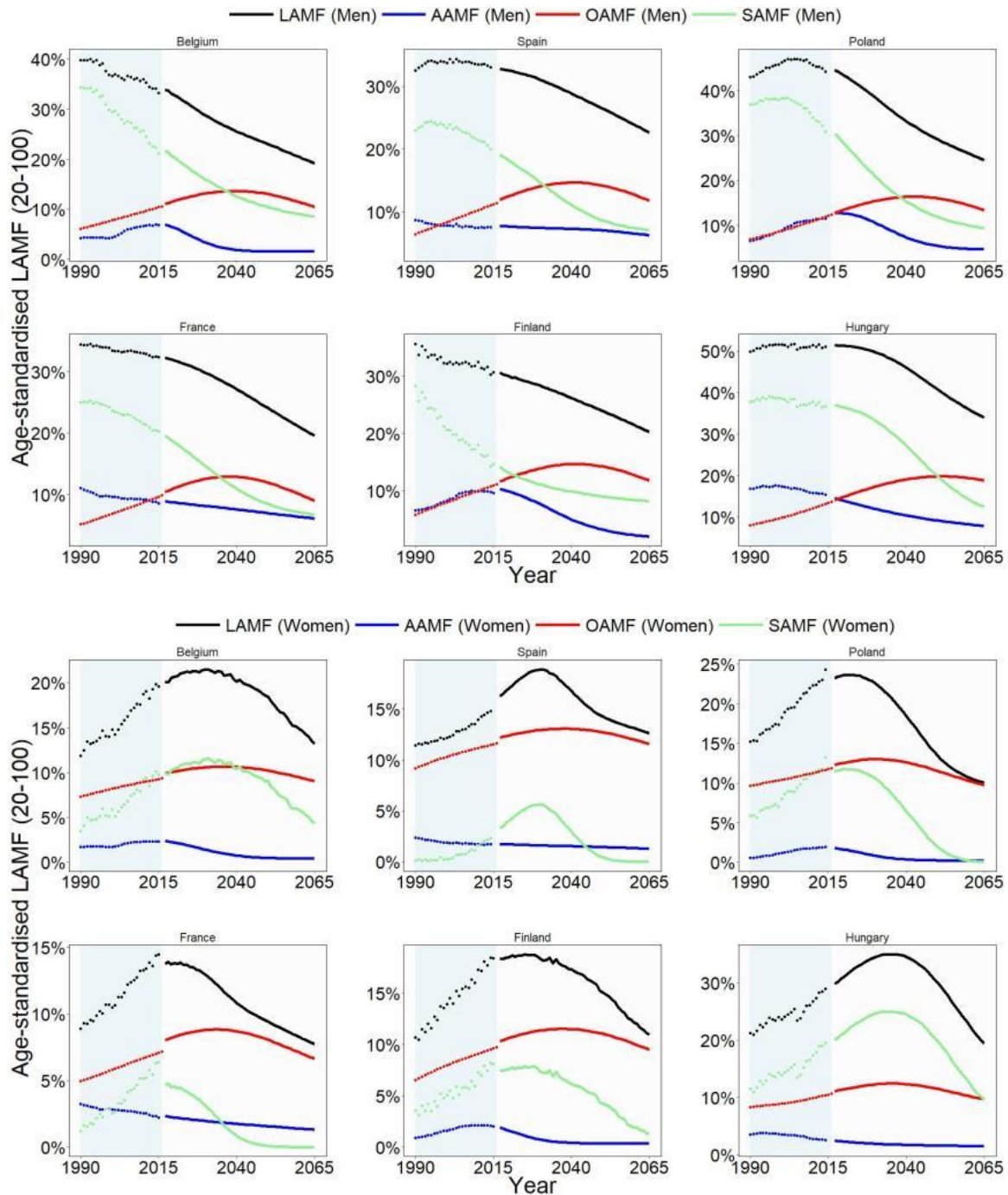
Figure 1   **Comparison of trends in life expectancy at birth (e0) for all-cause mortality with trends in e0 for non-lifestyle-attributable mortality (smoking, obesity, alcohol, combined), for six selected European populations, 1950-2016**

13. Figure 2 shows the projection of lifestyle-attributable mortality fractions, both separate and combined, from 2015-2065, for the six European countries, by sex. For the smoking-attributable

mortality fractions (SAMF) we project decelerating declines for men, and an increase followed by a decline for women. For the alcohol-attributable mortality fractions (AAMF), we project mostly decelerating declines, sometimes preceded by a peak. For the obesity-attributable mortality fractions (OAMF), we project an increase followed by a decline. For the three lifestyle factors combined we see a future decline for men, and a future wave pattern for women. For men this projected decline in LAMF is mainly due to smoking, but in later years also due to obesity. For women the shape of the wave pattern is driven by smoking, but it is elevated with the projected levels in particularly obesity.

Figure 2 **Projected lifestyle-attributable mortality fractions (smoking, obesity, alcohol, combined), 2015-2065, for six European countries by sex, ages 20-100**
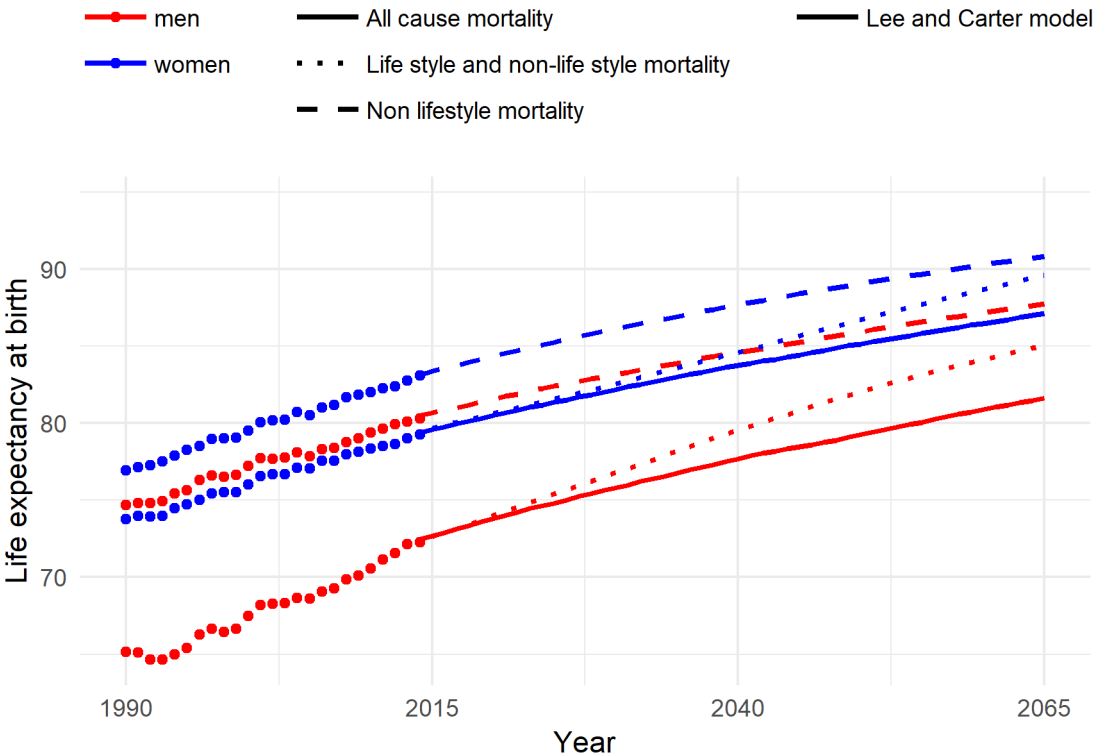

14. Figure 3 compares the different all-cause projections for Hungary. Figure 3a compares the individual Lee-Carter forecasts while taking into account lifestyle epidemics (non-lifestyle+lifestyle) with direct all-cause mortality projections (all-cause). Figure 3a illustrates that

the inclusion of lifestyle epidemics results in higher projected e0 values, both for men and women. The projected levels for e0 that takes into account lifestyle epidemics (non-lifestyle+lifestyle) move eventually back to the e0 level for nonlifestyle-attributable mortality, which can most clearly be observed for Hungarian men. For Hungarian men, when lifestyle-attributable mortality (declining over time) is added, a smaller future increase is projected compared to the direct projection of all-cause mortality. For Hungarian women, when lifestyle-attributable morality (increase followed by decline) is added, a slightly higher increase is projected compared to the direct projection of all-cause mortality. Combined, this results for Hungary in more convergence between the sexes when lifestyle factors are taking into account (4.5 years difference compared to appr. 5.5 years difference for the direct projection of all-cause mortality).

Figure 3 **Comparison of the different projections of life expectancy at birth (e0) for Hungary, by sex, 2015-2065**
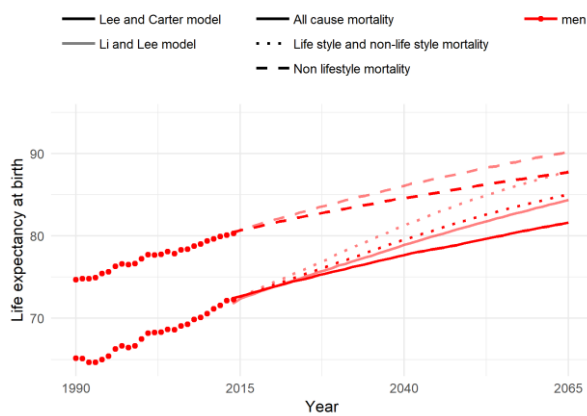
a) Effect of the inclusion of lifestyle epidemics when individually forecasting mortality
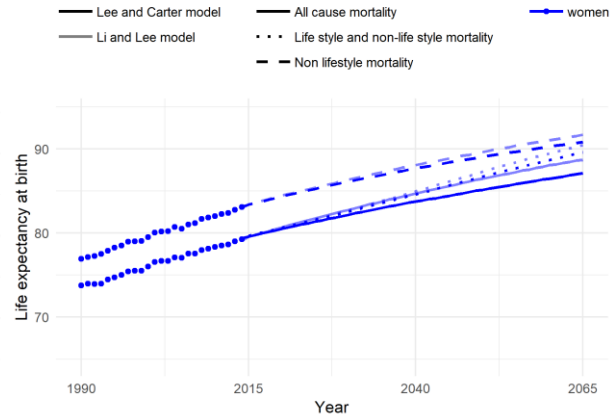
15. Figure 3b illustrates the effect of coherently forecasting mortality for Hungary by integrating the mortality experience among women in France, Spain and Italy. This results, logically, in higher future e0 especially among Hungarian men. For Hungarian women the effect of using the mortality experience among women in France, Italy and Spain is larger for the all-cause mortality projections compared to the non-lifestyle mortality projections.

16. Our coherent projection that takes into account lifestyle epidemics results, for Hungary, in higher e0 and smaller convergence between the sexes as compared to the direct coherent projection of all-cause mortality (Figure 3c): 2.2 years difference instead of 4 years difference in 2065.

b) Effect of the inclusion of the mortality experience in other countries (LC + LL comparison)
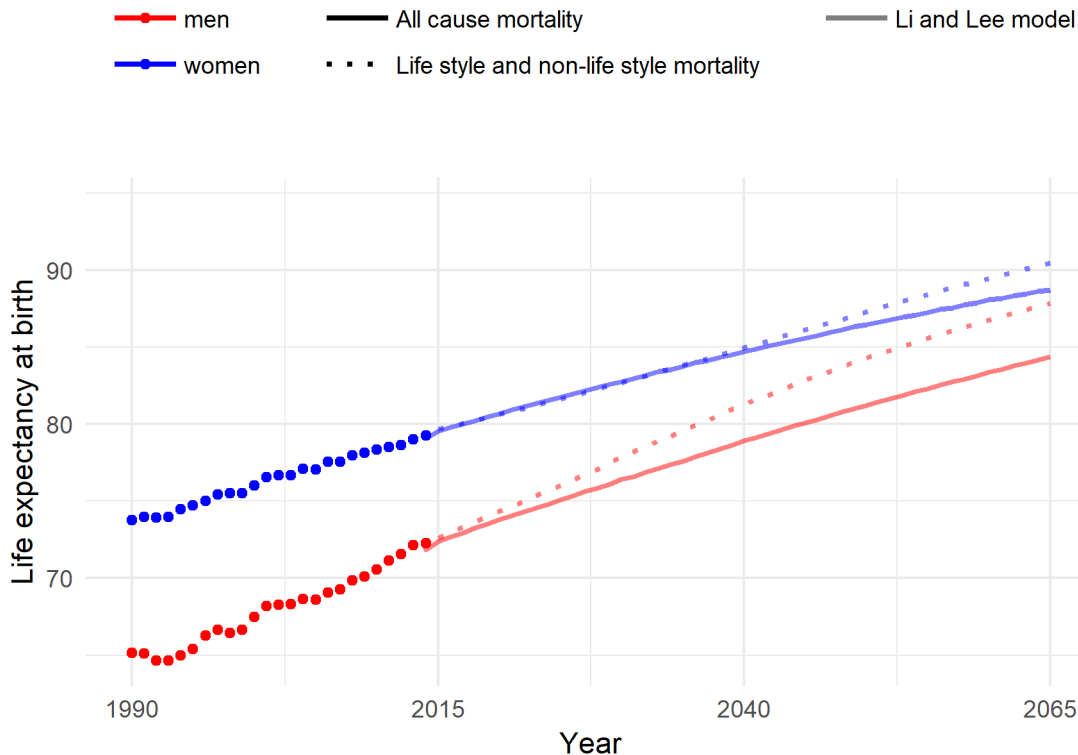
Men   **Women**

c) Effect of the inclusion of lifestyle epidemics when individually forecasting mortality

17. Figure 4 illustrates the effect of integrating lifestyle epidemics when individually forecasting mortality for two additional examples: Belgium women and Spain. Again we can observe the moving back to the trend for e0 for non-lifestyle-attributable mortality. In addition, as illustrated by Spain, we avoid unrealistic crossovers between e0 for all-cause mortality and e0 for non-lifestyle-attributable mortality. In these two examples, and in other western European countries, we in fact project less convergence between men and women when projecting e0 individually thereby taking lifestyle epidemics into account.

18. Table 1 shows the effect of taking into account lifestyle epidemics when coherently forecasting mortality, for the six selected European populations. All-in all, we see higher e0 levels and more convergence between men and women.

Figure 4   **Effect of integrating lifestyle epidemics when individually forecasting mortality, two examples**

Belgium women   **Spain**
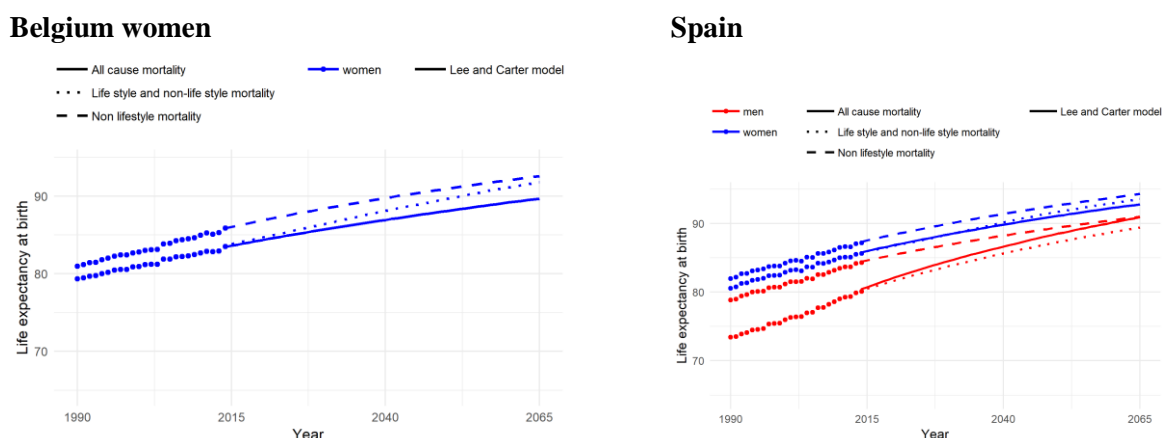

Table 1   **Effect of integrating lifestyle epidemics when coherently forecasting mortality on projected life expectancy at birth (e0) in 2065, six selected European countries, by sex**

	Men			Women			Women – Men		
		Projected e0 2065 Li and Lee			Projected e0 2065 Li and Lee			Projected e0 2065 Li and Lee	
	e0 2014	Allcause direct	Allcause indirect	e0 2014	Allcause direct	Allcause indirect	e0 2014	Allcause direct	Allcause indirect
Belgium	78.6	88.6	90.6	83.5	91.4	92.7	4.9	2.8	2.1
France	79.3	89.4	91.3	85.4	93.0	94.2	6.2	3.5	2.9
Spain	80.1	89.4	91.2	85.6	92.9	93.6	5.5	3.4	2.4
Finland	78.1	88.4	90.0	83.9	91.7	92.7	5.7	3.3	2.8
Poland	73.7	85.8	89.1	81.4	90.5	92.0	7.8	4.6	2.9
Hungary	72.3	84.4	87.8	79.2	88.7	90.4	7.0	4.3	2.6

IV   CONCLUSION

19. We observed in our analysis that the past increase in e0 (1990-2014) is less strong for non-lifestyle-attributable mortality compared to all-cause mortality among men, but slightly stronger among women. LAMF is projected to further decline among men and first to increase and then decline among women, mainly driven by the trends in smoking. When we integrate lifestyle epidemics in individual projections, future e0 (eventually) moves back to e0 for non-lifestyle-attributable mortality. Including lifestyle epidemics when coherently forecasting mortality results in higher e0 levels and more convergence between men and women.

20. From the current analysis it can be concluded that mortality projections that take into account likely future changes in smoking, alcohol and obesity result in higher future e0 values and - when projecting coherently - in larger convergence between the sexes.

21. All in all, the current work provides an important extension of my previous work in which I took into account the smoking epidemic when coherently forecasting mortality for the Netherlands (Janssen et al. 2013). This methodology has been taken over by Statistics Netherlands in their official population projection (Stoeldraijer et al. 2013b). Similarly we hope that the current method will also find its way in the mortality forecasting practice in Europe.

V   ACKNOWLEDGEMENTS

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