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IMPACTS OF CLIMATE CHANGE ON MORTALITY: AN EXTRAPOLATION OF TEMPERATURE EFFECTS BASED ON TIME SERIES DATA IN FRANCE

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Abstract. Most mortality models used in actuarial literature are based on historical trends, which may not account for the effects of climate change on future mortality. In this study, we introduce a new approach that combines the stochastic multi-population mortality model developed by Li and Lee with a distributed lag non-linear model (DLNM) from climate epidemiology to incorporate the effect of daily temperature variations into mortality projections. We apply this approach to French mortality and temperature data, and examine the projected loss in life expectancy due to temperature variations.

1. Introduction

According to the IPCC [16], climate change is expected to lead to significant changes in daily temperatures with major consequences for human health. In Europe, one of the predicted effects is the increase in intensity, severity, and duration of heatwaves,which is likely to lead to a rise in heat-related deaths [1]. Numerous studies highlight the contribution of extreme heatwaves to mortality [7, 9, 11, 15]. So far, heatwaves in Europe remain isolated events, and their impact on long-term trends in annual death rates is unclear. Nevertheless, most mortality models proposed in the actuarial or demographic literature do not incorporate the effects of climate change, see e.g. [2] for an explanation of their modeling approach. They are generally based on past trends, where the impact of climate change is still difficult to discern. Integrating the effects of climate change is therefore a crucial issue for insurers and pension funds, , as this topic has been understudied in the actuarial literature to date [18].

In this study, we aim to incorporate the effect of temperature variations on future projected mortality rates. Our approach consists of two components: a standard multi-population stochastic mortality model, namely the Li and Lee model [14], and a widely used climate epidemiology model, the distributed lag non-linear model (DLNM) [5, 6]. By coupling these two approaches and assuming no changes in the adaptation of the studied populations, our modeling framework enables the integration of climate scenarios to account for the effect of projected daily temperatures in mortality projections. We illustrate this novel approach using French temperature and mortality data, and assess the impact of climate change on projected life expectancy. For further details, refer to the full version of our working paper [10].

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2. Method

We first introduce some notation. Let $\mu_{x,t}^{(g)}$, $E_{x,t}^{(g)}$, and $D_{x,t}^{(g)}$ represent, respectively, the force of mortality, observed exposure to risk, and observed number of deaths for sex $g \in \{\text{female}, \text{male}\} = \mathcal{G}$ for individuals within the age range $[x, x+1)$ and during the calendar year $[t, t+1)$, where $x \in \mathcal{X} = \{x_{\min}, \ldots, x_{\max}\}$ denotes the set of integer ages, and $t \in \mathcal{T}_y = \{y_{\min}, \ldots, y_{\max}\}$ represents the set of calendar years considered. We define the crude central death rate of mortality $\widehat{m}_{x,t}^{(g)} = D_{x,t}^{(g)}/E_{x,t}^{(g)}$, and decompose the death counts into $\widetilde{D}_{x,t}^{(g)}$, the number of deaths unaffected by temperature effects, and $\bar{D}_{x,t}^{(g)}$, the number of deaths attributable to temperature variations. We express the central death rates as

$$\widehat{m}_{x,t}^{(g)} = \widetilde{m}_{x,t}^{(g)}(1 - \theta_{x,t}^{(g)})^{-1}, \tag{1}$$

where $\widetilde{m}_{x,t}^{(g)}$ and $\bar{m}_{x,t}^{(g)}$ respectively represent the central death rate unaffected by temperatures and the temperature attributable central death rate. The term $\theta_{x,t}^{(g)} = \dfrac{\bar{D}_{x,t}^{(g)}}{D_{x,t}^{(g)}}$ is the attributable fraction due to temperatures in year t at age x for sex g. Our modeling approach consists in two steps. First, we estimate $\theta_{x,t}^{(g)}$ using a DLNM model using daily average temperature and daily death counts. Second, we model $\widetilde{m}_{x,t}^{(g)}$ with a Li-Lee model, i.e.

$$\ln\ \widetilde{m}_{x,t}^{(g)} = A_x + B_x K_t + \alpha_x^{(g)} + \beta_x^{(g)} \kappa_t^{(g)}, \tag{2}$$

where K_t is a common unisex trend, $\kappa_t^{(g)}$ are specific dynamics by sex. The parameters A_x and $\alpha_x^{(g)}$ represent level parameters at age x for mortality, while the parameters B_x and $\beta_x^{(g)}$ modulate the trend of the logarithm of mortality rates by age and sex, respectively. To account for the temperature effect, the Li-Lee model is estimated using the following Poisson assumption with a log-link function under standard identifiable constraints, based on the conditional maximum-likelihood approach [17]

$$D_{x,t}^{(g)} \sim \text{Pois}\left(E_{x,t}^{(g)}(1 - \theta_{x,t}^{(g)})^{-1} \exp\left(\widetilde{m}_{x,t}^{(g)}\right)\right). \tag{3}$$

Finally, the vector $(K_t, \kappa_t^{(f)}, \kappa_t^{(m)})$ is modeled using a time series model under a coherence assumption to avoid divergence between male and female mortality rates in the long run.

3. Application on french data

We illustrate this approach using French daily mortality data [13] and yearly mortality data [12], as well as daily average national temperatures [3]. Our models are trained on data from the calibration period $\mathcal{T}_y = 1980, \ldots, 2019$ for the age group $\mathcal{X} = 0, \ldots, 105$. A DLNM model is fitted separately for each sex and for four different age buckets (0-64, 65-74, 75-84, and 85+), based on daily death counts and average temperatures over the period $\mathcal{T}_y$. The relationship between temperature and temperature-attributable daily death counts is modeled via a bi-dimensional spline function [8]. This function (Figure 1) corresponds to the cumulative relative risk of mortality, calibrated with a lag parameter of 21 days. Natural cubic splines with three internal knots are placed at the 10th, 75th, and 90th percentiles of the daily temperature distribution. These curves reveal various sensitivity responses to both extreme cold and heat variations in terms of excess mortality, across age groups and sexes.

Finally, we simulate central mortality rates over the period 2020-2100, incorporating temperature effects. By computing projected life expectancy at birth, we assess the loss in life expectancy due to temperature effects, as shown in Figure 2. We display losses related to both hot and cold effects for each year, as well as losses from extreme heat effects only. To achieve this, we use daily future temperature projections from twelve climate models [4] for three climate change scenarios (Representative Concentration Pathway [RCP]2.6, RCP4.5, and

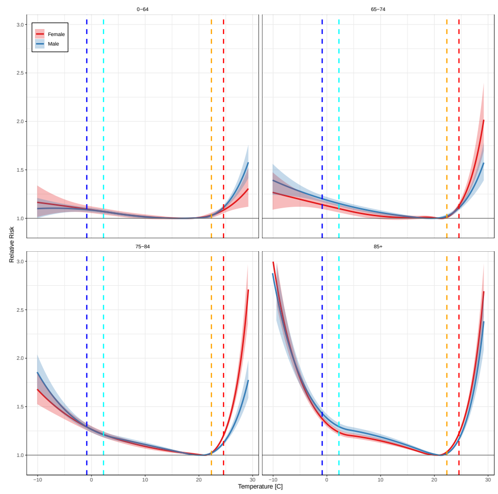

Figure 1. Cumulative relative risk of mortality over a 21-day with their 95% confidence intervals.

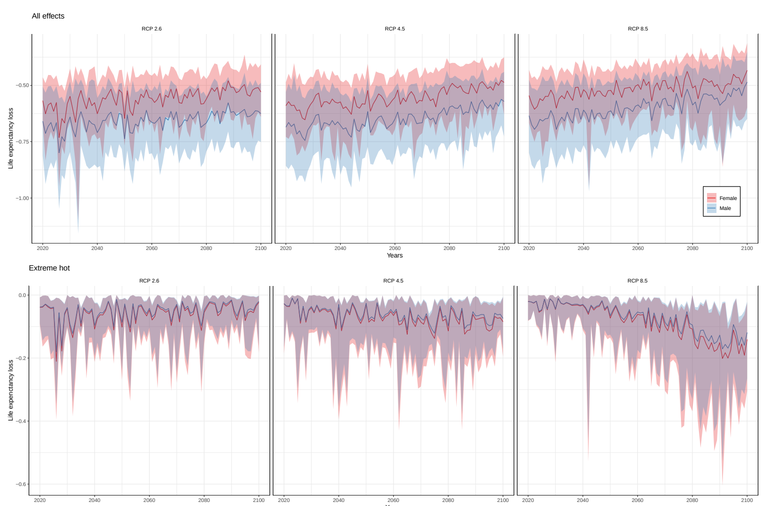

Figure 2. Life expectancy at birth lost in Metropolitan France, simulated for the years 2020-2100 for both women and men. We present both the loss related to all temperature effects and extreme hot effects only.

RCP8.5). In all three scenarios, we observe a general reduction in temperature-related life expectancy loss, explained by a reduction in cold-related mortality. However, in the RCP 8.5 scenario, life expectancy loss due to extreme heat increases from 2050 onward, which increases uncertainty in the projections.

4. Conclusion

In this work, we address the challenge of integrating temperature effects into mortality projections. Unlike traditional models used in actuarial science, our approach allows for the integration of future temperature adjustments into mortality projections through a DLNM model. This approach is illustrated using French data, where we assess the impact of temperature variations on life expectancy gains or losses under various climate scenarios.

The effect of temperature on mortality depends not only on geographic location but also on the population's ability to adapt. In this study, we make the strong assumption that populations do not adapt to their local environment. An interesting direction for future research is to explore this issue further.

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