Dynamic Forecast of US Life Expectancy at Birth within a Bayesian Framework

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Abstract

Forecasting US mortality is challenging, particularly for women. From the 1980s to the early 2000s, increases in life expectancy have fallen behind those of other high-income countries. It has been suggested that life style factors, especially smoking, are responsible for these slow increases. Since smoking prevalences are expected to decrease among younger birth cohorts, US mortality is likely to fall more rapidly in the future than during the last 30 years. Consequently, life expectancy will probably approach international trends again. We propose a novel method to forecast mortality, which uses rates of mortality improvement and combines objective and subjective information within a Bayesian framework. Besides a forecast until 2050, we demonstrate in a retrospective application that our approach would have resulted in more accurate estimates for US life expectancy than the original Lee-Carter model and two of its refinements proposed by Renshaw and Haberman.

Life expectancy at birth increases almost linearly in many highly developed countries (Oeppen and Vaupel, 2002; Tuljapurkar et al., 2000; White, 2002). Japan experiences the highest life expectancy at birth worldwide with 86.42 years for women and 79.61 years for men (in the year 2009 according to the Human Mortality Database (2013)). The ages, which contributed most to the increase in life expectancy, shifted from younger to older ages over time. It was estimated that about 40% of the increase in life expectancy in Japan, which can be considered a forerunner, between 1990 and 2007 was caused by mortality reductions at ages 80 and higher (Christensen et al., 2009).

Current US life expectancy lags behind international trends, though: In 2010, a newborn girl can expect to live on average 81.21 years, whereas a newborn boy can expect to live on average 76.37 years (according to the Human Mortality Database (2013)). As illustrated in Figure 1, those are average values across all countries of the Human Mortality Database but they are relatively low in comparison to other high-income countries. The trajectory of US life expectancy at birth is also rather irregular. While US life expectancy rose at the same pace as the leading countries from the 1950s until the 1980s, there were only minor increases observable from 1980 until the early 2000s. The last few years suggest a slightly stronger increase again.

According to the literature, smoking is the main culprit (e.g., Janssen et al., 2013; Preston and Wang, 2006; Wang and Preston, 2009), but also other factors, primarily related to lifestyle, are to be blamed for the slow increase. A panel of the National Research Council concluded:

> "Smoking appears to be responsible for a good deal of the divergence in female life expectancy. Other factors, such as obesity, diet, exercise, and economic inequality, also have likely played a role in explaining the current gap between the United States and other countries [. . .]"

National Research Council (2011, p. 144)

Consequently, plausible US mortality forecasts have to fulfill two requirements: *First*, they should be able to incorporate a dynamic shift in mortality reductions from younger to older ages. *Second*, they should allow an accelerating increase in female life expectancy at birth in the long run since smoking prevalence appears to decrease among younger birth cohorts (Preston and Wang, 2006).

Many common forecasting approaches fail to predict such a dynamic mortality development. For instance, the widely accepted Lee-Carter model (Lee and Carter, 1992) (and numerous of its variants) extrapolate past mortality trends with an inflexible age schedule of mortality change. This would lead to an implausible US mortality forecast, assuming that male life expectancy would approach (and exceed) female life expectancy in the (very) long run.

We propose a combination of recent ideas in a Bayesian framework. First, we account for dynamic changes in mortality via rates of mortality improvement rather than the typically used death rates. Those rates of improvement are defined as the time-derivative of age-specific death rates. Figure 2 depicts age-specific death rates (upper panels) and their rates of improvement (lower panels) in the United States from 1950 to 2010 for both sexes. We argue that the rates of improvement give a clearer picture of the underlying mortality dynamics than the death rates. For instance, the diagonal patterns in the lower panels suggest that the stagnating trend in female life expectancy at birth since the 1980s were mainly due to cohort effects. Renshaw and Haberman (2012) and Mitchell et al. (2013) pursue a comparable strategy: They apply the prediction structure of the original Lee-Carter model with the rates of mortality improvement to forecast mortality.

Second, our model allows us to optionally combine objective and subjective information. For instance, we can complement an extrapolated mortality trend of a country of interest with that of at least one reference country (which we consider to exhibit similar conditions regarding health and mortality). Such a trend modification is especially worthwhile if a purely extrapolated mortality trend in a country of interest does not meet our expectations; we can increase its plausibility by complementing it with mortality trends of other (subjectively) selected countries. Combining multiple mortality trends enables us to model nonlinear and dynamic mortality developments. To our knowledge, Li and Lee (2005) introduced the feature of joint trajectories of different populations to conduct coherent forecasts. We employ this optional feature in our out-of-sample mortality forecast for US females, because we do not expect the slow increase in life expectancy at birth from 1980–2005 will continue in the long run.

In our paper, we conduct two forecasts: In an in-sample forecast, we project US life expectancy at birth from 1991 to 2010 using observed mortality data from 1970 to 1990 from the Human Mortality Database (2013). This allows us to benchmark the forecasting performance of our model with that of the original Lee-Carter model (1992), with that of two of its variants proposed by Renshaw and Haberman (2003; 2006) and with the coherent forecast model by Li and Lee (2005).

To forecast mortality with the original Lee-Carter model and with three of its modifications, we use its freely available implementation by Timothy Miller[1], the *ilc R*-package (Butt and Habermann, 2010) and the web-based platform *lcfit* of the demography department of the University of California at Berkeley.[2]

Figure 3 illustrates that the forecasts of our model are much closer to the actually observed life expectancies at birth than the ones of the other four approaches. As shown in the lower lines, our model mirrors the development of life expectancy of men very closely, whereas the other approaches appear to systematically underestimate the actual values. All models perform better for males than for females (upper lines), probably due to the fact that mortality developed more regularly for men. In contrast, none of the models captured the slower increase in female life expectancy correctly, although our approach is closer to the actual development with substantially lower forecast errors.

Summarizing our in-sample forecast reveals that our model performs very well if mortality develops regularly (US males). We could have improved our forecast by complementing the irregular trend for females in the US with that of Denmark, whose period of mortality stagnation started earlier than in the US. We did not use such a trend for our in-sample forecast since using such additional information in hindsight would give our model a systematic advantage.

Next to this in-sample forecast, we also forecast US life expectancy at birth from 2010 to 2050, using observed mortality from 1970 to 2009 as the base period. Figure 4 depicts the results: According to our model, US life expectancy at birth is likely to reach almost 90 years for women and about 85 years for men in 2050. The Lee-Carter models as well as its two variants proposed by Renshaw and Haberman forecast slower increases in life expectancy at birth for both sexes. This effect is even stronger for females than for males.

We circumvent the continuation of the slow increase in female life expectancy during the base period by complementing the mortality trend of US females with that of Japanese, French, Italian and Swedish women, assuming that the US will catch up to international trends represented by those four countries. If we had not complemented the mortality trend

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[1] `http://www.demog.berkeley.edu/~tmiller/research/forecasts/mort.forecast.module.s`

[2] `lcfit.demog.berkeley.edu/`

of US females, the forecast of our model would be similar to that of the original Lee-Carter model.

The coherent approach by Li and Lee is one of the few existing models that can incorporate external mortality trends of other countries in a forecast. For a valid comparison with our model, we also include the international mortality trends of Japanese, French, Italian and Swedish women in the coherent mortality forecast for US females. As a result, the coherent approach by Li and Lee is much closer to our estimates of female life expectancy than the other models. Obviously, we would need to wait 37 more years to determine whose forecast will be closer to reality. Nevertheless, our model seems to be the only one, which allows an accelerating trend as we expected and has also been postulated by Wang and Preston (2009). In contrast, judging by our empirical estimates, the other models appear to project linear trends, differing only in their slopes.

Acknowledgement

The European Research Council has provided financial support under the European Community's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no. 263744.

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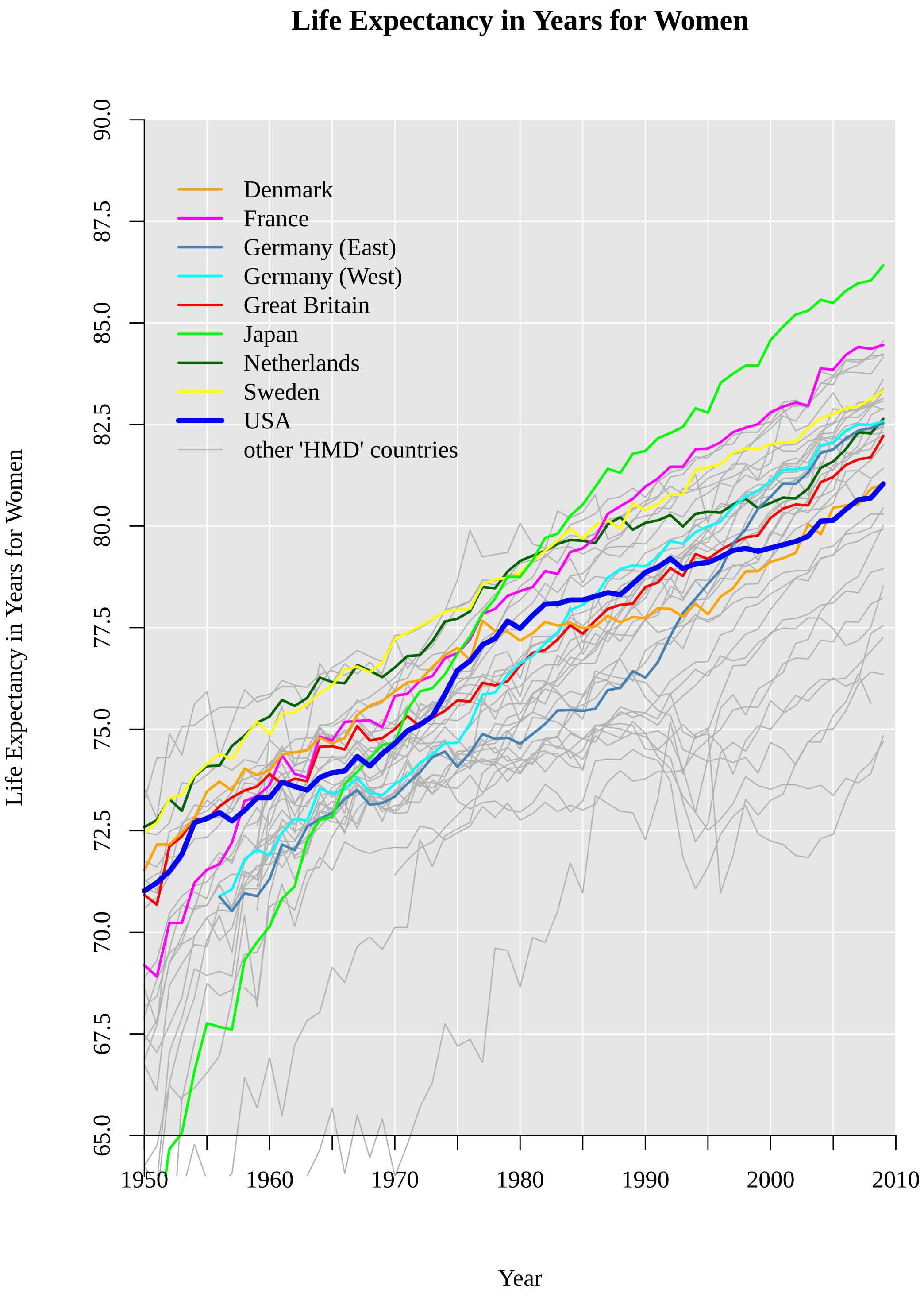

Figure 1: Life Expectancy in Years for Women in Selected Countries From 1950 until 2010. Source: Own estimation based on data from the Human Mortality Database (2013).

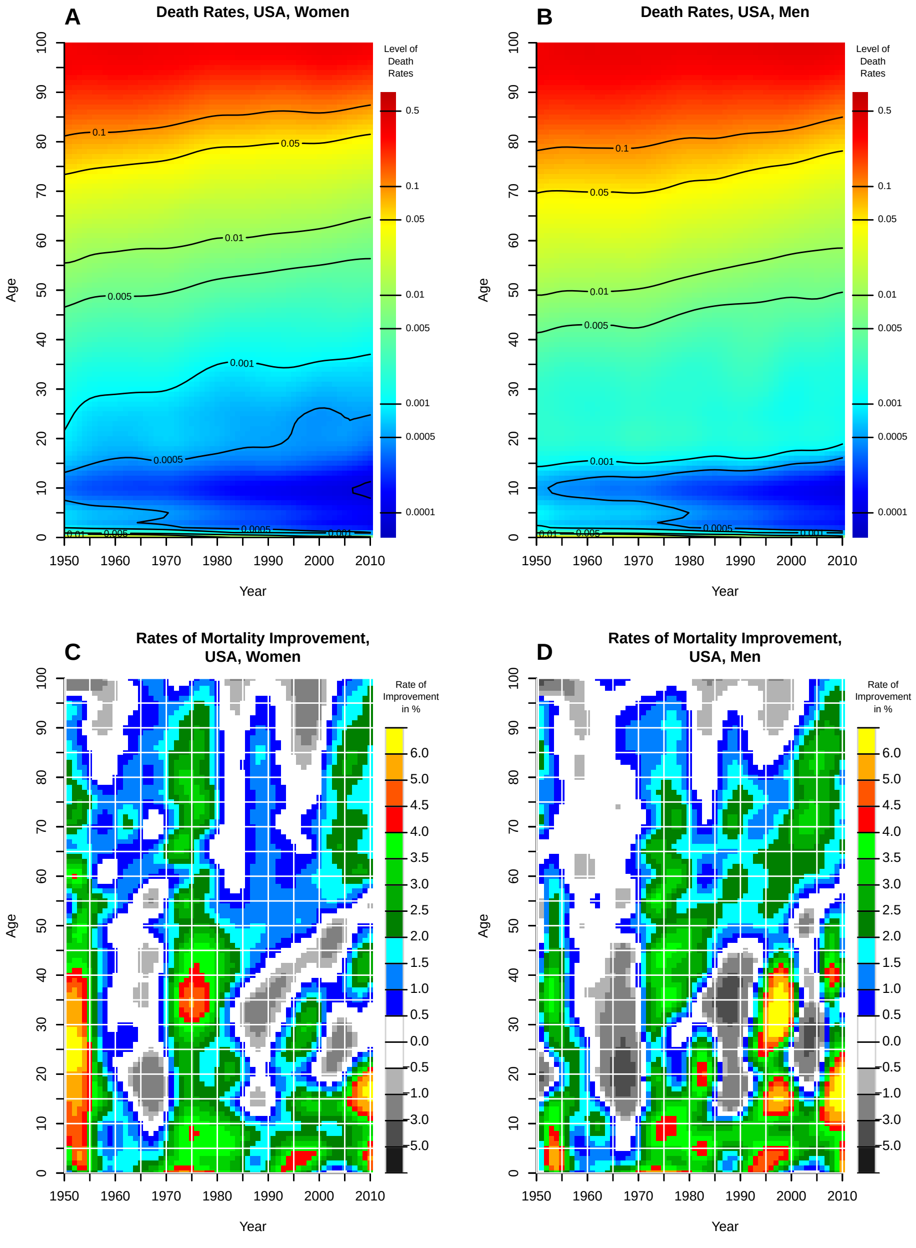

Figure 2: Upper Panel: US death rates for women (A) and men (B). Lower Panel: Rates of mortality improvement in the United States for women (C) and men (D). Source: Own estimation based on data from the Human Mortality Database (2013).

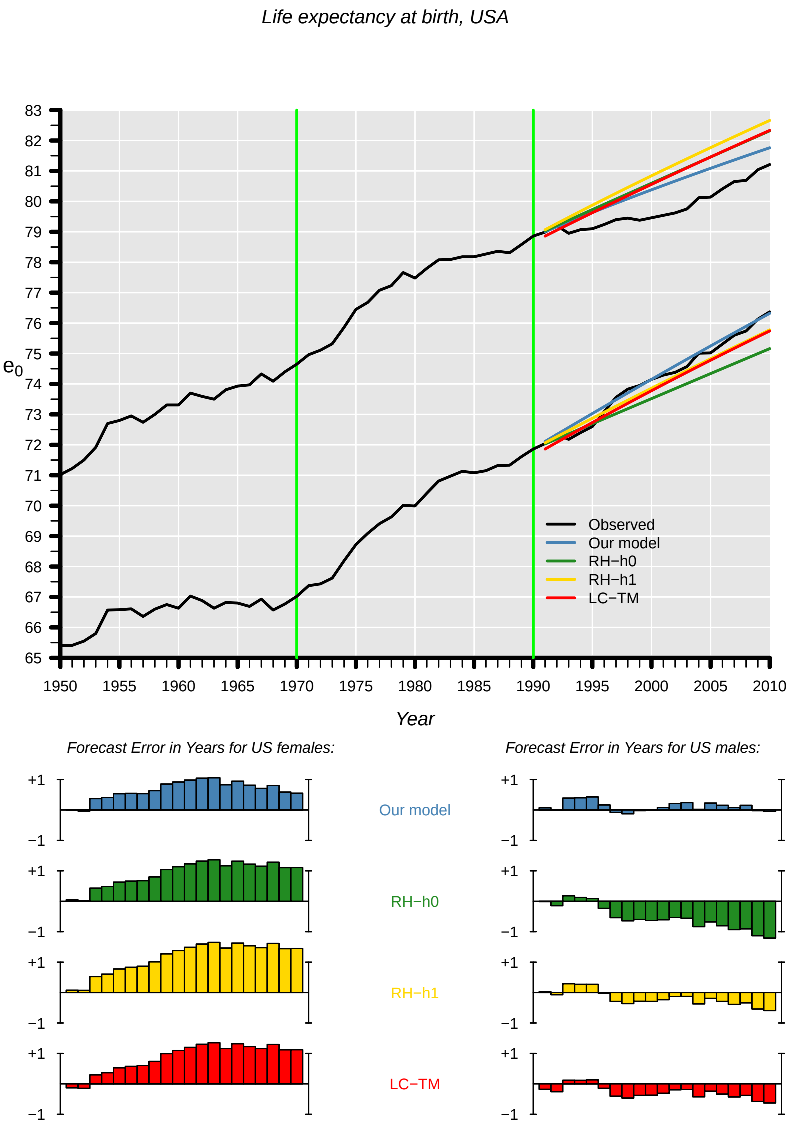

Figure 3: Observed (black) and forecasted life expectancy at birth (e_0) of our model (blue), of the original Lee-Carter model (red) and of its variants h0 (green) and h1 (yellow) proposed by Renshaw and Haberman for women (upper graph) and men (lower graph). For this in-sample forecast, we take mortality data from 1970 to 1990 (green vertical lines) in order to forecast them from 1991 to 2010. Comparing the forecast errors of all four models indicates that our model generates the smallest forecast errors for both sexes.

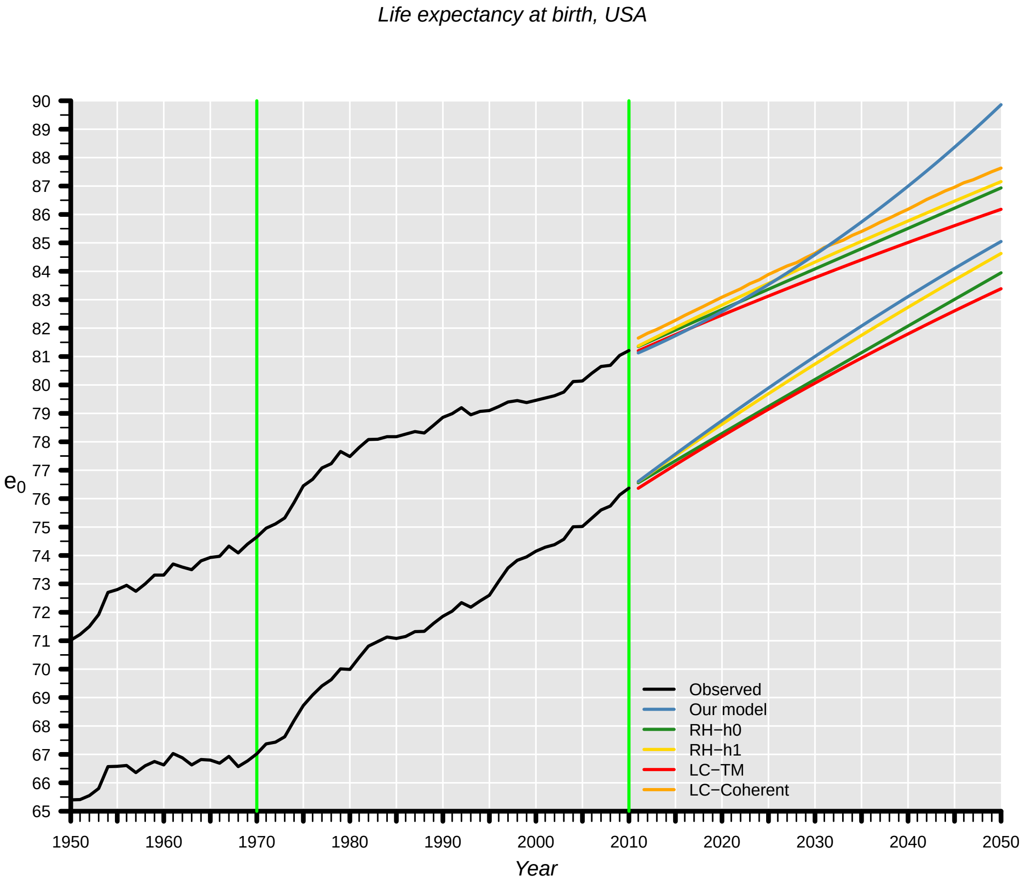

Figure 4: Observed (black) and forecasted life expectancy at birth (e_0) of our model (blue), of the original Lee-Carter model (red), of its coherent variant (orange) proposed by Li and Lee and of its variants h0 (green) and h1 (yellow) proposed by Renshaw and Haberman for women (upper graph) and men (lower graph). For this out-of-sample forecast, we take mortality data from 1970 to 2010 (green vertical lines) in order to forecast them from 2011 to 2050. In our model and in the coherent forecast, we complement the mortality trend for US females with that of Japanese, French, Italian and Swedish women.