Modelling and forecasting sex differences in mortality: a sex-ratio approach

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Abstract

Over the last three decades, male and female life expectancies have been converging in industrialized societies. This convergence is largely due to a greater mortality reduction for males. When forecasting mortality by sex, this catching up of males towards females needs to be acknowledged. We introduce a new method to model and forecast the sex-ratio of the age-specific death rates, based on principal components techniques. Our model allows us to visualize the age-structure and the general level over time of the sex difference in mortality, as well as forecast this difference. Based on a prior forecast for females, we can successfully forecast the male mortality catch up toward female mortality.

Key words: Coherent forecasts; mortality; male-female differences.

1 Introduction

Throughout the years, females have had longer life expectancies than males in industrialized societies. This difference in mortality between males and females emerges both from biological and nonbiological reasons.

The female biological advantage seems to come from the extra X-chromosome and female hormones (Luy, 2003). Naeye et al. (1971) found that the extra X-chromosome carried by females could confer a better immune response. This explanation seems however only relevant for infant mortality. Gordon et al. (1978) associate the increase of cardiovascular diseases after menopause as a sign that estrogen may provide some protection against these diseases (Nathanson, 1984).

The biological factors may play a role in sex differences in mortality, but they cannot explain the observed time and geographic variations (Gjonça et al., 1999; Nathanson, 1984). The role of environmental, social and behavioral factors also account for male-female differences in mortality (Meslé, 2004; Waldron, 1995). For different historical, psychological and cultural reasons, men and women tend to have different health related behaviors and medical access. In industrialized countries, women tend to be more advantage than men in terms of health-related behaviors (Meslé, 2004). Smoking habits seem to explain a great part of the mortality gap between sexes (Gjonça et al., 1999).

Before the 1940s, sex differential in life expectancy was quite steady and started increasing afterwards in favor of women (Luy and Wegner-Siegmundt, 2013). Since the 1970s, the gap in mortality between females and males has started to decrease. This is mainly the result of a convergence between sexes in terms of health-related behaviors (Meslé, 2004; Trovato and Lalu, 2007).

When forecasting mortality by sex, the catching up of males towards females needs to be considered. As mentioned by Li and Lee (2005), forecasting separately the mortality of two populations tends to increase their divergence on the long run, even when using similar extrapolative procedures. Thus, mortality for females and males should not be forecast independently and coherence between sexes should be accounted for. When forecasting coherently mortality for males and females, an extra constraint should also be considered: as females have a biological advantage, females can be expected to keep having lower mortality than males in the future.

In this paper, we suggest a new method to forecast mortality coherently between sexes using principal components techniques and the sex-ratio of the age-specific death rates. Our method allows us to forecast coherently male and female mortality while acknowledging the female advantage.

This paper is divided into five sections, with this introduction as first section. In the next section, we introduce the method and state the underlying assumptions. The data used are then reported. In the fourth section, the results are presented for 20 industrialized countries. The parameters are first analyzed, followed by an evaluation of our method, in comparison with other forecasting models, and finally we present the mortality forecasts until 2050. The discussion and conclusion are included in the final section.

2 Methodology

We suggest to forecast male mortality using the logarithm of the sex-ratio of the age-specific death rates (ASDR) and principal components analysis. The sex-ratio of the ASDR has been a commonly used indicator to study mortality differences between females and males, as it offers a clearer picture of the differences by age than the absolute sex-difference of the ASDR (Beltrán-Sánchez et al., 2015; Meslé, 2004). Hyndman et al. (2013) also use sex-ratio to forecast mortality based on a product-ratio method. We suggest however to forecast male mortality based on a prior female forecast:

$$ln\left(\frac{m_{x,t}^{M}}{m_{x,t}^{F}}\right) = \alpha_x \gamma_t \tag{1a}$$

or

$$m_{x,t}^{M} = m_{x,t}^{F} e^{\alpha_x \gamma_t}, \tag{1b}$$

where $m_{x,t}^{F}$ and $m_{x,t}^{M}$ are the age-specific death rates (ASDR) for females and males respectively and α_x and γ_t are found with a singular value decomposition (SVD) applied to the matrix of the logged sex-ratios by age and over time, as presented in equation (1a) :

$$\gamma_t = us\Sigma v \tag{2a}$$

$$\alpha_x = \frac{v}{\Sigma v}, \tag{2b}$$

where u is the first left singular vector, s is the leading singular value and v is the first right singular vector of the SVD. The SVD allows us to decompose the sex-ratio matrix into an age- and time-index. The α_x is an age-profile of the sex-ratio and indicates the intensity of the mortality difference by age. The γ_t is a time-profile of the sex-ratio and indicates the general level of the sex gap at time t.

To forecast mortality with the model presented in equation (1a), the ASDR for one of the gender should be forecast beforehand with any mortality-forecasting model by age (e.g. Lee and Carter (1992) model). As female mortality has evolved more linearly than male's over time, female forecasts are generally more accurate. We thus suggest to forecast female mortality beforehand and then forecast male ASDR using equation (1). However, we will also evaluate the performance of the forecast when male mortality is forecast first and female mortality is forecast using equation (1a).

In the above equations, the male age-specific death rates change proportionally with the female's, meaning that, as long as the female ASDR are decreasing, the male ASDR will also keep decreasing. This implies that mortality improvement observed among females will also be noticed among males, but at a different level. The parameters α_x and γ_t should be positive, such that the male ASDR do not cross over the female's. The term $e^{\alpha_x \gamma_t}$ will thus be higher than 1, ensuring that the female mortality is lower than male mortality.

Male mortality can be forecast by extrapolating the time-factor γ_t using time-series methods, similar to the Lee and Carter (1992) approach. The γ_t term is not, in the context of sex difference, a linear trend. It rather looks as a bell-shaped curve: the sex gap of the ASDR has increased until the beginning of the 1990s and then started to decrease. To avoid the crossover between males and females, the γ_t should always be positive. We suggest to forecast γ_t with an autoregressive (AR) model with intercept.

3 Data

The data source is the Human Mortality Database (HMD, 2015), which offers high quality historical mortality data for industrialized countries. The method is applied to forecast the mortality of 20 of the HMD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, New-Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States. We use the period data on age-specific death rates (not smoothed) from 1960 until 2008.

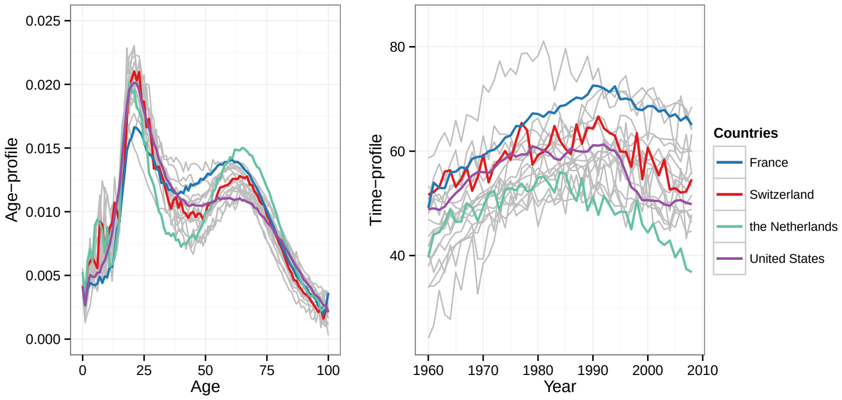
4 Results

4.1 Parameters analysis: 1960-2008

4.1.1 International comparison

Figure 1 presents the age-profile (α_x) and time-profile (γ_t) of the sex-ratio for 20 industrialized countries. We highlighted four countries: France, Switzerland, the Netherlands and the United States. The time-profile indicates the general level of the sex-ratio over time. The male-female mortality ratio has been increasing until the beginning of the 1990s and has since started to decrease for most countries. Some countries such as Finland, France, Spain and Portugal recorded a rather high level of mortality difference between males and females. On the opposite, the Netherlands, Sweden and the United Kingdom kept a relatively low level.

Figure 1: Age-profile and time-profile of the ASDR sex-ratio between 1960 and 2009 for 20 industrialized countries



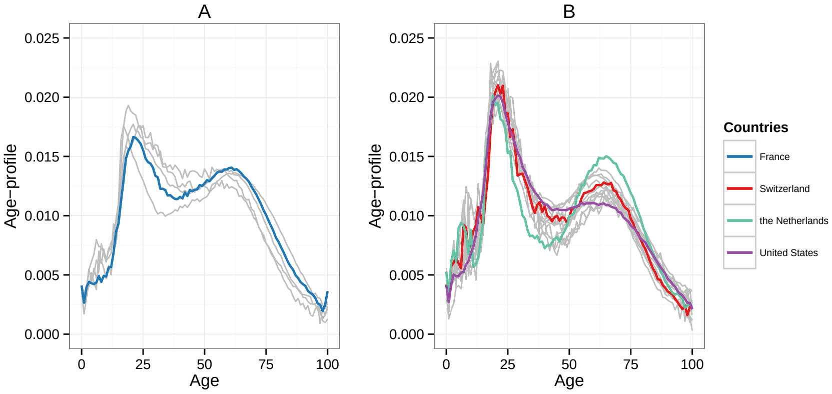
Source: HMD (2015) and author's own calculation.

The age-profile of the mortality sex-ratio is represented by a bi-modal curve; with the first mode appearing around age 20; and the second mode, around age 65. The sex difference in mortality thus principally come from differences at young adult ages (15-30 years old) and at middle-old ages (50-70 years old).

The bi-modal shape seems however more pronounced for some countries than for others. Five countries (Finland, France, Japan, Spain and Portugal) have a smaller first mode and less pronounced minimum around the age of 45. The panel A of Figure 2 emphasizes this result.

The panel B of Figure 2 presents the age-profile for the 15 remaining countries. The first mode of the age-profile seems to be highly constant across these countries. However, more variations are observed for the second mode and before age 15. The first mode can thus reflect an inherent process, while the second mode could be more changeable. To evaluate this hypothesis, we analyze the change through time of the age-profile in the next section.

Figure 2: Two age-profile groups of the ASDR sex-ratio between 1960 and 2009 for 20 categories.

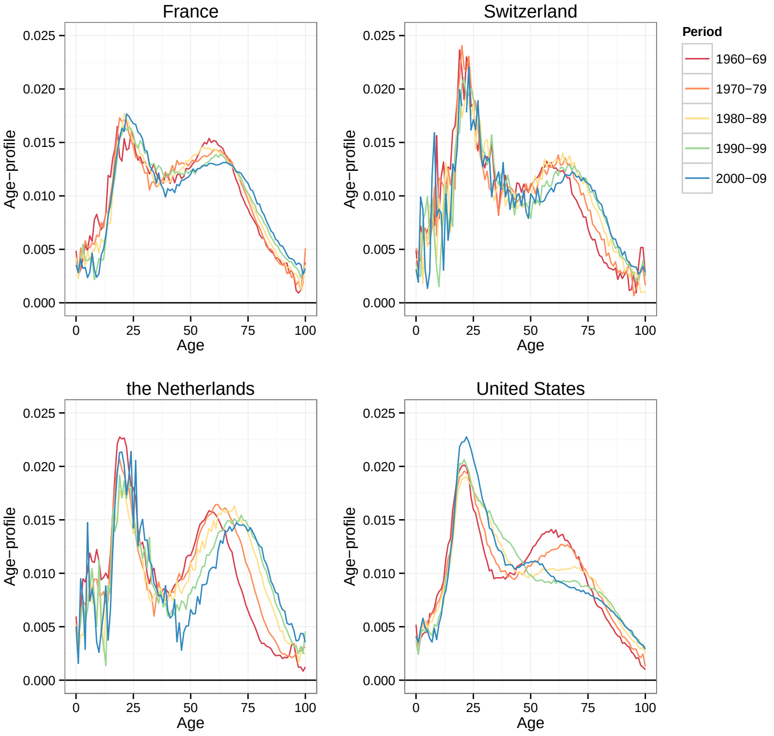


Source: HMD (2015) and author's own calculation.

4.1.2 Change over time of the age-profile

The change over time of the age-profile is illustrated by Figure 3 for four countries. Since 1960 and for most countries, the age-pattern (α_x) kept a bi-modal shape across time-periods. The first mode seems to be relatively constant over time, with some exceptions, including countries highly touched by AIDS in the 1980s and 1990s, as Italy, Spain, Portugal, France and the United States.

Figure 3: Age-profile the ASDR sex-ratio estimated over 5 time-periods, France, Switzerland, the Netherlands and the United States



Source: HMD (2015) and author's own calculation.

More variations in time are however observed for the second mode. A postponement of the second mode is observed for many countries, suggesting a delay in the male-female differences. The second mode seems also to disappear for the United States, Denmark and the United Kingdom in the most recent years. A more detailed analysis would be needed to explain these variations, which is beyond the scope of this study.

These results confirm the previous statement that the second mode is more changeable, while the first mode is roughly constant over time and between countries and might highlight a more deep-rooted process.

When forecasting mortality, considering the change in the age-pattern might be necessary. However, we show in Appendix A that, for most countries, assuming a constant α_x for the forecast leads to similar results than using a moving α_x. In the following sections, we forecast the sex-ratio in mortality using a constant age-pattern estimated from the whole reference period.

4.2 Evaluating the forecasts

One way to evaluate a forecast model is to use an older reference period to forecast actual mortality. For both sexes, we forecast the life expectancy for the years 1990 to 2008, based on the reference period 1960-1989, and compare our results with the observed values. We compare our model, using different prior methods, with existing forecasting models. We classify the forecast models into three categories: Sex-independent models, sex-ratio coherent model and other sex-coherent models.

1. The sex-independent models are forecast models which do not consider the coherence between males and females: Lee and Carter (1992), Li and Lee (2005) (using an average for industrialized countries), Compositional Data Analysis forecast (CoDa) (Oeppen, 2008) and a CoDa-coherent model, using an average for industrialized countries (Bergeron-Boucher et al., 2014).
2. Sex-ratio coherent model is defined in equation (1). The prior models used are the four independent models defined in 1.
3. The other sex-coherent models are models considering the coherence between sexes, and which have been previously developed: Li-Lee (using an average for males and females mortality), CoDa-coherent model (using an average for males and females mortality) and the Hyndman, Booth and Yasmeen model (HBY) (Hyndman et al., 2013).

4.2.1 Females

Table 1 presents the average for 20 industrialized countries of the mean absolute error (MAE) of the female life expectancy at birth forecast for the period 1990-2008. In general, the sex-independent models would have performed better for females. However, which of the four independent models would have been the best is not obvious. This result is further illustrated by Figure 4 for French females life expectancy.

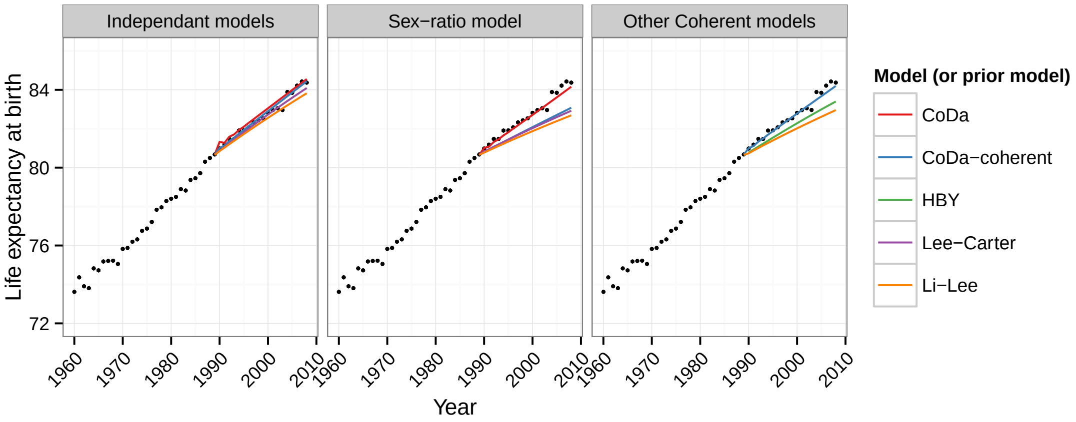
Using a sex-coherent models tends to underestimate or increase the underestimation of life expectancy at birth for females, when comparing with the independent models. Sex-coherent models would have performed better for only six countries: Canada, Denmark, Japan, the Netherlands, Norway and the United States (Appendix B). Some of these countries recorded slower increase of the female life expectancy at birth. This last aspect might explains why models leading to more pessimistic forecasts perform better for these countries.

Table 1: Average for 20 industrialized countries of the mean absolute error (MAE) of the female life expectancy at birth forecast from 1990 to 2008 with 11 models and number of countries recording the lowest MAE by model

	Sex-independent models				Sex-coherent models						
					Sex-ratio model (prior models used for males)				Other coherent models		
	LC	LL	CoDa	CoDa-C	LC	LL	CoDa	CoDa-C	LL	CoDa-C	HBY
Average MAE	0.52	0.49	0.75	0.54	1.06	0.98	1.12	0.90	0.70	0.55	0.70
Nb countries	3	3	4	4	1	0	2	1	1	1	0

Source: HMD (2015) and author's own calculation.
Note: Details on country-specific performance under each of the models is found in Appendix B.

Figure 4: French female life expectancy at birth forecast for the period 1990-2008 using 11 models



Source: HMD (2015) and author's own calculation.

4.2.2 Males

Table 2 presents the average for 20 industrialized countries of the MAE of the male life expectancy at birth forecast for the period 1990-2008. The results for males differ than those for females. The independent models perform rather poorly. The coherent models tend to perform better and especially the sex-ratio model. Similar results are presented in Figure 5. Using a sex-ratio model, with CoDa-coherent models as a prior model for females, would have offered the most accurate forecast for males for the selected forecast period.

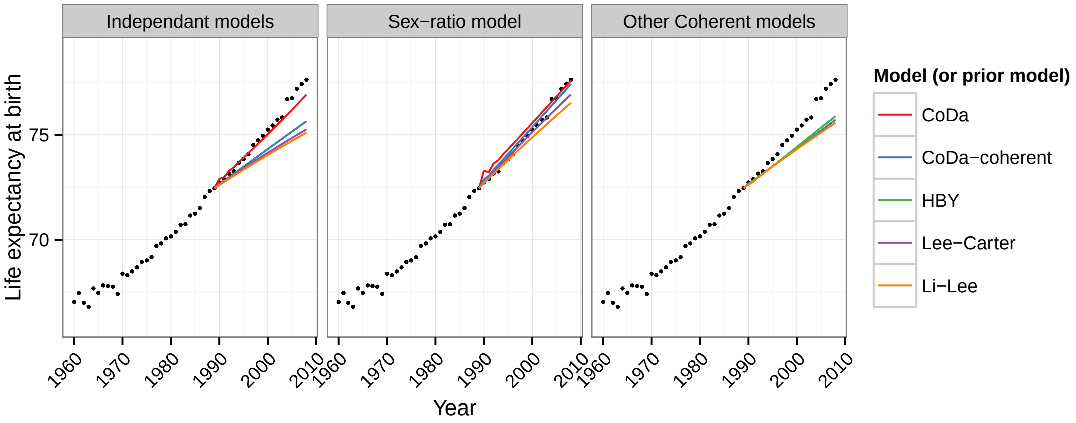
These results suggest that forecasting females mortality independently to males' and then using the sex-ratio model presented in equation (1) to forecast males mortality would have led to more accurate forecast. According to the results in Tables 1 and 2, using the CoDa-coherent model to forecast females mortality would have performed relatively well for females and seems to be the most accurate prior female forecast when forecasting male mortality with the sex-ratio model. In the following section, we will use the CoDa-coherent model to forecast females mortality until 2050.

Table 2: Average for 20 industrialized countries of the mean absolute error (MAE) of the male life expectancy at birth forecast from 1990 to 2008 with 11 models and number of countries recording the lowest MAE by model.

	Sex-independent models				Sex-coherent models						
					Sex-ratio model (prior models used for females)				Other coherent models		
	LC	LL	CoDa	CoDa-C	LC	LL	CoDa	CoDa-C	LL	CoDa-C	HBY
Average MAE	1.44	1.19	1.56	1.05	0.81	0.55	0.95	0.51	0.97	1.03	1.08
Nb countries	0	0	0	0	1	2	6	9	1	1	0

Source: HMD (2015) and author's own calculation.
Note: Details on country-specific performance under each of the models is found in Appendix B.

Figure 5: French male life expectancy at birth forecast for the period 1990-2008 using 11 models



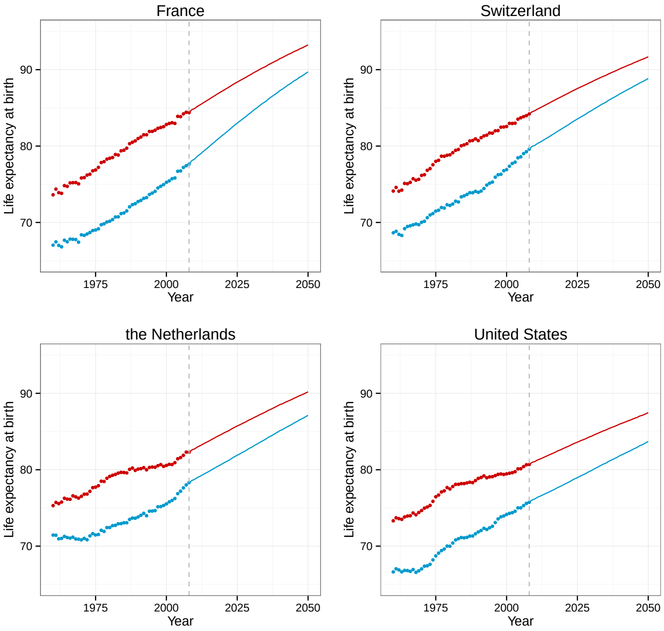
Source: HMD (2015) and author's own calculation.

4.3 Mortality forecasts until 2050

Equation (1) can be used in a forecasting context if one of the sex mortality has been forecast beforehand. We forecast female mortality using a compositional data analysis (CoDa) procedure, introduced by Oeppen (2008) in the context of mortality forecasting, which integrates a factor of coherence among countries (Bergeron-Boucher et al., 2014) (Details of this forecasting procedure are available from the authors). For the male forecast, we use equation (1) and forecast the time-factor γ_t using an autoregressive (AR) model of order 2 with intercept.

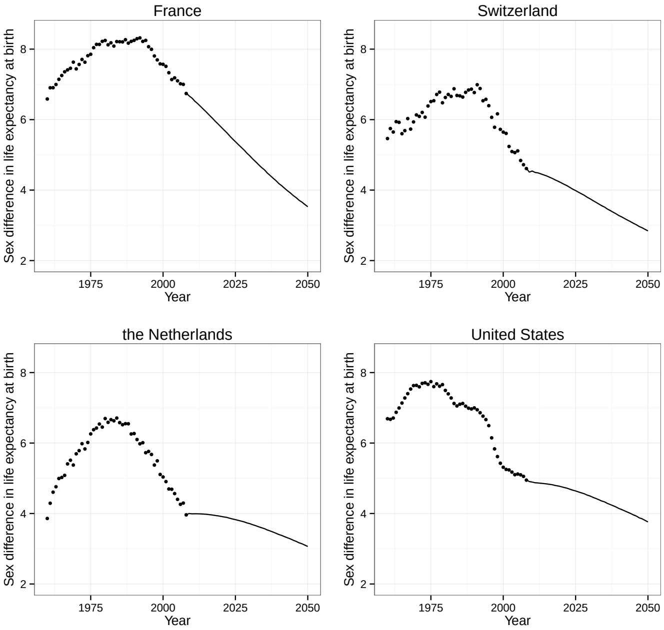
Figure 6 presents the results for France, Switzerland, the Netherlands and the United States and for both sexes. The reference period is 1960-2008 and the mortality is forecast until 2050. Our model allows male life expectancy at birth to catch up on female's, as further illustrated by Figure 7. By 2050, our model predicts that the difference in life expectancy between females and males will be 3.5 years in France, 2.8 in Switzerland, 3.1 in the Netherlands and 3.8 years in the United States.

Figure 6: Life expectancies at birth observed (dots) and forecast (lines) for males (in blue) and females (in red), 1960-2050, France, Switzerland, the Netherlands and the United States.



Source: HMD (2015) and author's own calculation.

Figure 7: Sex difference in life expectancy at birth observed (dots) and forecast (line), 1960-2050, France, Switzerland, the Netherlands and the United States



Source: HMD (2015) and author's own calculation.

5 Discussion and Conclusion

The model introduced in this paper hypothesizes that male mortality evolves proportionally to female ASDR. This assumption implies that males and females benefit from similar improvements in living conditions and medicine and suffer similar obstacles to bring mortality further down. This also implies that, as the ASDR at ages where the sex-difference is the greatest (15-30 and 50-70 years old) are decreasing, the sex gap in life expectancy can be expected to record a large reduction in the future.

With our model, the male forecast is based on a prior female forecast. The accuracy of the male forecast thus depends on the accuracy of the selected forecast model for females. As a consequence, the uncertainty of the female forecast will be reflected in the male forecast. However, the results section on the evaluation of the model shows that using the sex-ratio model presented in this paper, using any of the four prior models compared, would have generally led to more accurate forecast than previously developed sex-coherent models.

Using a prior female forecast gives some flexibility to our model. The methodology presented can be combined with any mortality-forecasting model for females by age. Irrespective to the prior female forecast method selected, the male mortality can be forecast coherently with females.

One weakness of the model could be that γ_t is more strongly influenced by ages were the ASDR sex-ratio is the highest. The age-group 15-30 is thus having an important impact on γ_t. However, the main changes in mortality occur at older ages in more recent years and the γ_t trends might not capture perfectly the changes in the sex-ratio at these influential ages.

Despite these limitations, our model is able to explained a great deal of the variance in the ASDR sex-ratio (over 90% for most countries) and would have been able to predict more accurately the recent male mortality trends than other sex-coherent and independent models.

In summary, we introduced a new mortality forecast model for males which is coherent with a female forecast. The model ensures that female mortality keeps being lower than male mortality to preserve the biological advantage of females while considering the male catch up on female mortality.

Future steps of this project will assess the optimal way of incorporating uncertainty in our forecasts.

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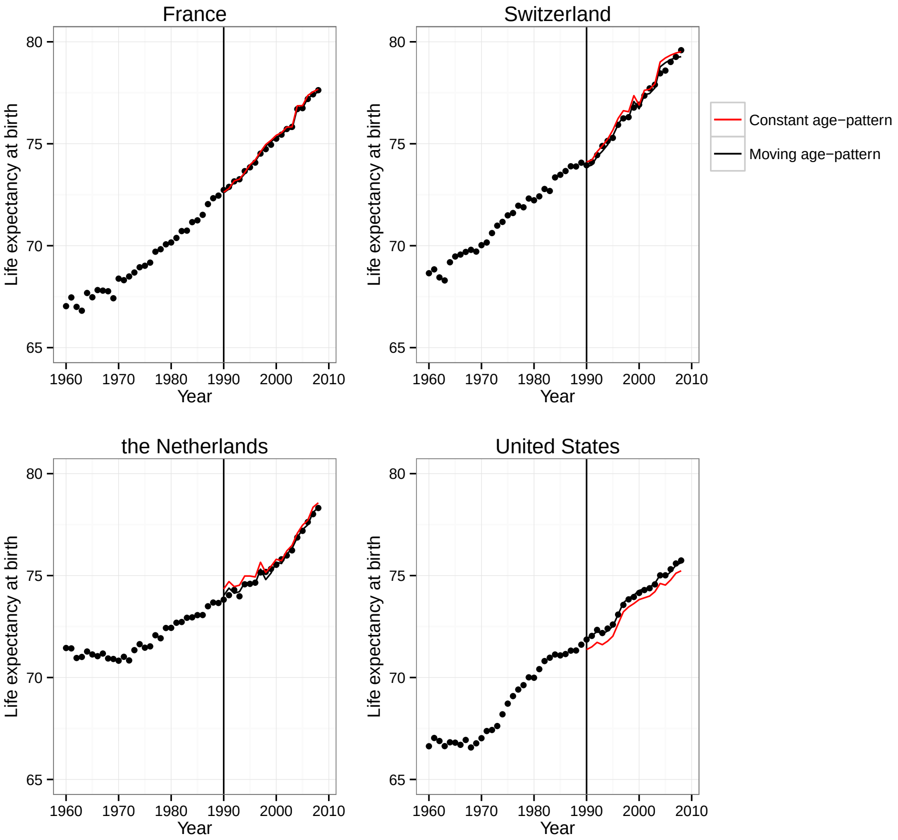
A Effect of changing the age-profile on life expectancy forecasts

In section 4.1.2, we showed that the second mode of the age-profile is not always constant over time. In this section, we look at the effect of considering a moving age-pattern in contrast with a constant age-pattern for the forecasts. We forecast male mortality for the period 1990-2008, based on the reference period 1960-1989. To avoid the potential errors of forecasting γ_t and female mortality incorrectly, we make the hypothesis that we are able to predict female mortality and γ_t perfectly, using the observed and estimated values for the period 1990-2008. We here compare two scenarios:

1. The age-pattern α_x is changing over time, and we can perfectly predict how. We thus use the estimated α_x for the periods 1990-1999 and 2000-2008.

2. The age-pattern is staying constant in time and is equal to the estimated α_x for the period 1960-1989.

Figure 8: Male life expectancy at birth forecast using a constant and moving age-pattern of the mortality sex-ratio, 1990-2008, France, Switzerland, the Netherlands and the United States



Source: HMD (2015) and author's own calculation.

Figure 8 shows that, while considering a moving age-pattern leads to more accurate forecast, assuming a constant α_x over time would have lead to very similar results for three countries out of four. As shown by Figure 3, the age-pattern for France has stayed quite constant in time and thus, assuming a constant age-pattern would be a reasonable assumption for this country. In Switzerland and the Netherlands, the second mode of α_x is shifting in time. However, assuming a constant α_x leads to similar results than a moving α_x. These results suggest that, in absence of a strong assumption on how the age-pattern might change in the future, assuming a constant α_x might be a "safe choice" for the forecast. Finally, the age-pattern of the United States has known great modifications over time. Correcting the age-pattern might then be necessary for this country. However, how the age-pattern of the sex-ratio in mortality will change is still an open question and a deeper comprehension on why α_x is changing would be necessary.

B Mean absolute errors (MAE) for 20 countries

Table 3: Mean absolute error for 20 industrialized countries resulting from forecasting female life expectancy from 1990 to 2008 with 11 models, based on the reference period 1960-1989

	Sex-independent models				Sex-coherent models						
					Sex-ratio model (prior models used for males)				Other coherent models		
	LC	LL	CoDa	CoDa-C	LC	LL	CoDa	CoDa-C	LL	CoDa-C	HBY
Australia	1.00	0.94	0.49	0.56	1.57	1.80	1.70	1.53	1.33	0.66	0.88
Austria	0.61	0.51	0.85	0.54	1.20	1.26	1.35	1.19	0.88	0.64	1.05
Belgium	0.12	0.17	0.12	0.11	0.81	0.78	0.46	0.64	0.53	0.21	0.57
Canada	0.28	0.41	0.60	0.96	0.26	0.22	0.93	0.12	0.14	0.79	0.30
Denmark	0.53	0.45	0.50	1.04	1.28	0.46	1.10	0.33	0.33	0.87	0.87
Finland	0.36	0.62	0.62	0.78	1.23	1.46	1.42	1.33	0.92	0.92	0.69
France	0.19	0.31	0.21	0.12	0.78	0.92	0.17	0.73	0.80	0.14	0.56
Germany	0.55	0.49	0.16	0.52	1.29	1.15	1.10	1.10	0.86	0.63	0.45
Ireland	1.00	0.50	1.88	0.69	2.08	1.56	2.46	1.65	0.95	0.78	1.48
Italy	0.23	0.37	0.12	0.31	1.06	1.07	1.29	1.05	0.75	0.42	0.40
Japan	0.55	0.73	1.79	0.50	0.32	1.51	0.19	1.31	1.06	0.61	0.20
Netherlands	0.54	0.71	0.73	0.98	0.34	0.43	0.38	0.48	0.45	0.84	0.41
New-Zealand	1.76	0.99	1.97	0.61	2.42	1.97	3.15	1.98	1.29	0.72	1.94
Norway	0.62	0.20	1.36	0.18	1.47	0.57	1.48	0.43	0.57	0.15	1.24
Portugal	0.41	0.38	1.09	0.39	0.91	0.93	1.24	0.95	0.59	0.43	0.66
Spain	0.26	0.43	0.23	0.29	1.33	1.10	1.14	0.91	0.82	0.45	0.42
Sweden	0.13	0.38	0.77	0.32	0.93	0.58	1.05	0.39	0.28	0.21	0.46
Switzerland	0.10	0.16	0.50	0.34	0.87	0.95	0.65	0.74	0.47	0.19	0.34
United Kingdom	0.70	0.16	0.51	0.12	0.89	0.82	0.92	0.74	0.56	0.19	0.88
United States	0.49	0.87	0.58	1.38	0.21	0.17	0.15	0.39	0.47	1.22	0.26
Average	0.52	0.49	0.75	0.54	1.06	0.98	1.12	0.90	0.70	0.55	0.70
Nb countries	3	3	4	4	1	0	2	1	1	1	0

Table 4: Mean absolute error for 20 industrialized countries resulting from forecasting male life expectancy from 1990 to 2008 with 11 models, based on the reference period 1960-1989

	Sex-independent models				Sex-coherent models						
					Sex-ratio model (prior models used for females)				Other coherent models		
	LC	LL	CoDa	CoDa-C	LC	LL	CoDa	CoDa-C	LL	CoDa-C	HBY
Australia	1.93	2.25	2.09	1.92	1.23	1.20	0.70	0.79	1.98	1.91	1.61
Austria	1.40	1.47	1.60	1.39	0.64	0.58	0.93	0.60	1.22	1.37	1.20
Belgium	0.89	0.88	0.64	0.75	0.26	0.27	0.25	0.20	0.71	0.77	0.50
Canada	1.02	0.99	1.86	0.79	0.57	0.41	0.31	0.19	0.83	0.74	0.64
Denmark	1.94	0.82	1.78	0.65	1.00	0.25	0.76	0.69	0.62	0.64	1.55
Finland	1.38	1.66	1.64	1.51	0.21	0.53	0.52	0.70	1.42	1.51	0.72
France	1.05	1.15	0.29	0.89	0.24	0.41	0.33	0.20	0.90	0.86	0.80
Germany	1.36	1.24	1.19	1.18	0.66	0.62	0.32	0.64	1.00	1.19	0.50
Ireland	1.76	1.19	2.25	1.30	0.66	0.61	1.51	0.55	0.94	1.32	1.11
Italy	1.20	1.23	1.47	1.16	0.37	0.52	0.24	0.43	1.01	1.13	1.07
Japan	1.19	0.46	1.69	0.26	2.18	0.58	3.63	0.94	0.30	0.23	1.70
Netherlands	1.37	0.74	1.49	0.66	0.70	0.44	0.52	0.29	0.50	0.62	0.88
New-Zealand	2.83	2.25	3.67	2.27	1.96	1.00	2.24	0.59	2.01	2.27	2.51
Norway	2.46	1.38	2.48	1.25	1.60	0.99	2.39	0.65	1.17	1.18	1.70
Portugal	0.78	0.72	1.01	0.70	0.94	0.83	0.86	0.71	0.60	0.70	0.59
Spain	1.26	0.90	0.98	0.61	0.41	0.14	0.46	0.19	0.68	0.57	0.34
Sweden	1.56	1.11	1.72	0.86	0.60	0.17	1.37	0.12	0.88	0.83	1.28
Switzerland	1.40	1.45	1.16	1.19	0.48	0.57	0.35	0.41	1.21	1.15	0.66
United Kingdom	1.33	1.27	1.38	1.19	1.20	0.50	1.02	0.45	1.02	1.18	1.55
United States	0.59	0.70	0.79	0.41	0.32	0.29	0.27	0.85	0.43	0.37	0.69
Average	1.44	1.19	1.56	1.05	0.81	0.55	0.95	0.51	0.97	1.03	1.08
Nb countries	0	0	0	0	1	2	6	9	1	1	0