Future life expectancy in 35 industrialised countries: projections with a Bayesian model ensemble

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Summary

Background Projections of future mortality and life expectancy are needed to plan for health and social services and pensions. Our aim was to forecast national age-specific mortality and life expectancy using an approach that takes into account the uncertainty related to the choice of forecasting model.

Methods We developed an ensemble of 21 forecasting models, all of which probabilistically contributed towards the final projections. We applied this approach to project age-specific mortality to 2030 in 35 industrialised countries with high-quality vital statistics data. We used age-specific death rates to calculate life expectancy at birth and at age 65 years, and probability of dying before age 70 years, with life table methods.

Findings Life expectancy is projected to increase in all 35 countries with a probability of at least 65% for women and 85% for men. There is a 90% probability that life expectancy at birth among South Korean women in 2030 will be higher than 86·7 years, the same as the highest worldwide life expectancy in 2012, and a 57% probability that it will be higher than 90 years. Projected female life expectancy in South Korea is followed by those in France, Spain, and Japan. There is a greater than 95% probability that life expectancy at birth among men in South Korea, Australia, and Switzerland will surpass 80 years in 2030, and a greater than 27% probability that it will surpass 85 years. Of the countries studied, the USA, Japan, Sweden, Greece, Macedonia, and Serbia have some of the lowest projected life expectancy gains for both men and women. The female life expectancy advantage over men is likely to shrink by 2030 in every country except Mexico, where female life expectancy is predicted to increase more than male life expectancy, and in Chile, France, and Greece where the two sexes will see similar gains. More than half of the projected gains in life expectancy at birth in women will be due to enhanced longevity above age 65 years.

Interpretation There is more than a 50% probability that by 2030, national female life expectancy will break the 90 year barrier, a level that was deemed unattainable by some at the turn of the 21st century. Our projections show continued increases in longevity, and the need for careful planning for health and social services and pensions.

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Introduction

In high-income countries, except in periods of war, famine, and infection outbreaks, national life expectancy has increased steadily for decades, although there has been stagnation or decline in poor and marginalised groups.[1–3] At the same time, due to variations in the pace of increase, the country with the highest (frontier) life expectancy has changed several times.[3]

Projections of future mortality and life expectancy are needed to plan for health and social services and pensions. Most current mortality and life expectancy projections rely on a single model, selected based on either theoretical considerations or a comparison of a few models.[4] Due to differences in methodology, such projections vary across studies. For example, some researchers have projected a continued rise in life expectancy in high-income countries.[3,5] Others have argued that obesity and other risks to health will imminently (ie, within the first half of the 21st century) halt or reverse the rise in life expectancy.[6] This discrepancy indicates that there is uncertainty about model choice, which is not taken into account when a single model is used.

We applied a probabilistic Bayesian model averaging (BMA) approach to mortality and life expectancy projection.[7] The BMA approach, which is increasingly common in areas of science such as weather and climate forecasting, uses an ensemble of models, all of which probabilistically contribute towards the final projections.

Methods

Countries analysed

Our analysis covered high-income countries in Asia and the Pacific, North America, central Europe and western Europe, as well as Latin American countries that are members of the Organisation for Economic Co-operation and Development (OECD), with data available on deaths and population from 1985 to 2010 or later, and a population of 1 million or more over the entire period. Having data from at least 1985 provided a sufficient number of years to estimate parameters and weights for the models as described below. The table

Research in context

Evidence before this study
We searched PubMed for articles published up to July 21, 2016, with no language restrictions, using the search terms "forecasting" OR "projection", "Bayesian", and "life expectancy" in the publication title and abstract. We also used a review of forecasting methods to identify previous studies. All identified studies had used a single preferred model for projecting mortality or life expectancy or both for one or multiple countries.

Added value of this study
In a novel approach, we used an ensemble of models, all of which probabilistically contribute toward the final projections, with the projections from each model weighted according to how well it predicted withheld data for each country and sex. This approach not only takes into account the inherent uncertainty in the choice of projection model, but also outperforms projections from the single-model approach. We also decomposed the projected rise in life expectancy into gains in younger, middle, and older ages.

Implications of all the available evidence
There is a high probability that life expectancy will continue to increase in all industrialised countries, and more than a 50% chance that by 2030 national female life expectancy in South Korea will break the 90 year barrier. Enhanced longevity in older ages will be the main contributor to the projected gains in life expectancy at birth, especially in women.

lists the countries together with details about data availability.

Data sources
We obtained data on population and deaths from WHO. We obtained data for a single year (2014) for South Korea from the South Korean Statistical Information Service (KOSIS) because the latest year reported to WHO was 2013 at the time of analysis. All countries had data from 1985 onwards; 24 countries had data from 1960 onwards and were used for testing the performance of BMA projections. Information about data pre-processing is described in the appendix (p 3).

For more on **KOSIS** see http://kosis.kr/eng/

See **Online** for appendix

Bayesian model averaging
The probabilistic BMA approach uses an ensemble of models, each providing a posterior distribution for life expectancy in the future. The posterior distribution of the final projections is a probabilistic combination of those from individual models.[7]

We used an ensemble of 21 models for projecting age-specific death rates, which were in turn used to calculate projected life expectancy. These models, described in detail in the appendix (pp 4–6), were formulated to incorporate features of death rates in relation to age and birth cohort, and over time, as well as statistical considerations such as extent of smoothing over age and birth cohort, and how much weight to give to older data-points compared with more recent ones. We determined which models received a greater or lesser weight in the final projections based on performance in projecting withheld data in the following steps.

For the **code used for the analysis** see https://github.com/vkontis/maple

In step 1, we measured the performance of projections from individual models. We held back the last 13 years of data for each country (table), and used the remaining data to estimate model parameters, which we then used to make projections for the withheld years; 13 years is the maximum duration that would still allow sufficient data to reliably estimate model parameters for countries whose data start in 1985. We used bias in life expectancy, calculated as described in the appendix (p 7), as the metric to measure projection error for reasons described in the appendix (p 10). We calculated projection bias as the difference between the observed (but withheld) and projected life expectancies, averaged over all years of withheld data.

In step 2, we calculated model weights such that models with smaller bias were assigned larger weights, with the weights decaying exponentially as the magnitude of the projection bias increased. Each model was assigned a weight of exp(–|Projection bias|), where the bias was calculated as described in step 1; the 21 weights were normalised to sum to 1. The model weights are shown in the appendix (pp 16, 17).

In step 3, we calculated the final projections. We used all the available data for each country and sex to estimate model parameters, which we used to make projections to 2030. We took a number of draws from the posterior distribution of age-specific death rates under each model proportional to the weight of that model calculated in step 2, and pooled the draws to obtain the posterior distribution of age-specific death rates under the BMA, which were then used to calculate life expectancy projections. The code used for the analysis is available online.

We tested the performance of the BMA projections as described in the appendix (pp 8, 9), which showed that the BMA approach on average had a smaller error than the best single models for different sex, country, and projection duration combinations (appendix pp 18, 19). The relative advantage of the BMA compared with the best model increased for longer validation periods. For a projection duration of 22 years, the average absolute bias of the BMA across countries and years was 0·68 years for women and 1·09 years for men; that of the best model was 1·00 years for women and 1·39 years for men. The 90% coverage of the BMA projection uncertainty, which