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Projections of future life expectancy in China up to 2035: a modelling study

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Summary

Background To plan social and health services, future life expectancy projections are needed. The aim of this study was to forecast the future life expectancy for mainland China and its provinces.

Methods Following the same approach as the Global Burden of Disease Study, we used the largest compiled epidemiological and demographic datasets to estimate age-specific mortality and evaluate population data from 1990 to 2019. A total of 21 life expectancy forecasting models were combined by a probabilistic Bayesian model to forecast the life expectancy for mainland China and its provinces in 2035.

Findings The projected life expectancy at birth in mainland China in 2035 is 81·3 years (95% credible interval 79·2–85·0), and there is a high probability that the national goals of improving life expectancy will be achieved (79 years in 2030, and over 80 years in 2035). At the provincial level, women in Beijing have the highest projected life expectancy in 2035 with an 81% probability of reaching 90 years, followed by Guangdong, Zhejiang, and Shanghai, which all have more than a 50% probability of surpassing 90 years. Men in Shanghai are projected to have the highest life expectancy at birth in 2035, with a 77% probability of life expectancy being over 83 years, the highest provincial life expectancy in mainland China in 2019. The projected gains in life expectancy are mainly derived from older individuals (aged ≥65 years), except those in Xinjiang, Tibet, and Qinghai (for men), in which the main contributions come from younger (0–29 years) or middle-aged (30–64 years) individuals.

Interpretation Life expectancy in mainland China and its provinces has a high probability of continuing to increase through to 2035. Adequate policy planning of social and health services will be needed.

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See Online for appendix

Introduction

Projecting future life expectancy is an important component of planning health and social services and pensions.[1] These projections are usually for an individual country or compared between multiple countries. However, mortality and life expectancy vary widely within a country. Subnational planning and priority setting for public health and health-care systems require local life expectancy projections.

Life expectancy information at the provincial level is particularly important for a large country such as China. Improving life expectancy is one of the important goals of the Healthy China 2030 plan[2] and one of the key goals of the 14th Five-Year National Health Plan.[3] China has already improved the health status of more than 1 billion citizens;[4] however, health outcomes remain geographically dependent,[4] and life expectancy projections for subnational units within a country are rare and tend to be based on a short period of time in individual subnational units.[5] There is a need for life expectancy forecasts at the subnational level to help inform future health policies and programmes to achieve the national health goals.

Most previous studies used a single model to project future life expectancy; however, the results vary across studies due to uncertainty in model selection.[6] We used a probabilistic Bayesian model averaging (BMA) approach to estimate future life expectancy, which would make life expectancy predictions by considering an ensemble of models. Furthermore, we used the largest scale demographic datasets to assess the long-term trends of mortality and life expectancy in the past three decades in mainland China and its provincial units and project its future trends.

Methods

Data sources

All-cause mortality data were mainly derived from four data sources housed in the Chinese Center for Disease Control and Prevention (CDC), including the Disease Surveillance Point system, Maternal and Child Health Surveillance system, censuses, and demographic surveys (the One-per-Thousand Population Fertility Sample Survey, the Intercensal Survey, and the Annual Survey on Population Change).[4] We used the suite of data processing procedures developed by the Global Burden of Disease Study 2019 to generate data on age-specific all-cause mortality at the national and provincial levels. We provide a broad overview of these methods in the appendix (pp 1–2).

Research in context

Evidence before this study

We search PubMed for articles published from database inception up to Aug 18, 2022, with no language restrictions. The search terms "life expectancy" OR "longevity", "forecasting" OR "projection", and "China" were used for the publication title and abstract. We also used the same search terms for papers published in Chinese in the China National Knowledge Infrastructure (CNKI). Some attempts have been made to project life expectancy for the national population. Life expectancy projection for subnational units within a country is rare and tends to be a short period in individual subnational units. To our knowledge, there have been no studies on life expectancy projections for all subnational units within China.

Added value of this study

To the best of our knowledge, this study is the first to provide forecasts of life expectancy for all provincial levels within mainland China. In this study, we used the largest epidemiological and demographic datasets compiled to reflect life expectancy in mainland China, including censuses, the Disease Surveillance Point system, the Maternal and Child Health Surveillance system, and demographic surveys (the One-per-Thousand Population Fertility Sample Survey, the Intercensal Survey, and the Annual Survey on Population Change). In addition, an ensemble of models was used according to Bayesian model averaging to forecast future life expectancy, which considered all results from different models. To identify the growth model of life expectancy, the forecasted gain in life expectancy was also decomposed into young, midlife, and older ages.

Implications of all the available evidence

Life expectancy has a high probability of continuing to increase in China, and there is a high probability that the national goals of improving life expectancy will be achieved (79 years in 2030 and over 80 years in 2035). In some provinces (Beijing, Guangdong, Zhejiang, and Shanghai), the life expectancy of women has a more than 50% probability of reaching 90 years in 2035. The increase in life expectancy will have implications for planning and financing social and health care.

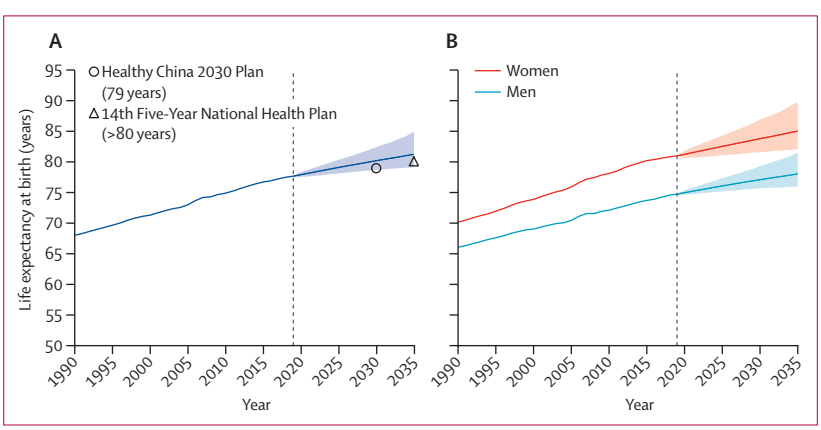


Figure 1: **Trends and projections of life expectancy in mainland China**
(A) Life expectancy in mainland China for both sexes. The solid purple line shows the life expectancy, and the light purple fan shows the predicted 95% credible interval. The hollow black circle indicates the goal of the Healthy China 2030 Plan for life expectancy, and the hollow black triangle indicates the goal of the 14th Five-Year National Health Plan for life expectancy. (B) Life expectancy in mainland China for women and men. The solid red and blue lines show the life expectancy for women and men, respectively, and the light red and blue fans show the predicted 95% credible intervals. The dashed vertical line indicates the beginning of the projection

The population sizes for mainland China and its 31 provinces were estimated as one unit. National census data were used to estimate populations, and an improved four-level Bayesian hierarchical model was used to estimate sex-age-year-specific populations to ensure maximum internal consistency.[4,7] For the Bayesian hierarchical model, level 1 modelled the difference between non-baseline sex-age-year-specific census counts and the corresponding projected counts, level 2 transformed the model inputs to projected sex-age-year-specific population counts, level 3 modelled the initial estimates of migration and the baseline population, and level 4 defined various hyperpriors. We provide a broad overview of these procedures in the appendix (p 2).

The mortality impacts of COVID-19 have decreased in many countries, especially for those with a large proportion of the population vaccinated against the virus (over 90% of people in China have received the first dose of a COVID-19 vaccine).[8,9] In line with the UN's assumption, we assumed that the life expectancy at birth would return to the prepandemic trajectory in 2022.[8] National and provincial-specific mortality and population data from 1990 to 2019 were collected to make life expectancy projections.

Our analysis covered 31 province-level units in mainland China, including 22 provinces, four municipalities, and five autonomous regions, all of which we refer to as provinces in this study. Due to changes in the provincial level of administrative units (eg, Hainan, Guangdong, Sichuan, and Chongqing), we reviewed all original data sources and separated them to match current province boundaries (appendix p 7).

Statistical analysis

Following the method described by Kontis and colleagues,[6] we used the probabilistic BMA approach to estimate future life expectancy. Probabilistic BMA can probabilistically combine the posterior distribution for life expectancy of multiple individual models. In this study, 21 individual life expectancy projection models were included in the probabilistic BMA approach, which incorporated features of mortality related to age, time period, and birth cohort, as well as statistical considerations, such as giving suitable weights to recent data. In addition, this approach has a smaller projection

error on average, which improved the validity of the projections.[6] These models included two age-time models, four weighted likelihood age-time and age-time-cohort models, eight piecewise linear age and age-time-cohort models, two age-time-cohort models, and five Lee-Carter models (appendix p 26). Detailed descriptions of these methods were given in a previous study.[6] Each model was weighted based on its projection bias.

Three steps were performed to project future life expectancy. First, we measured the performance of each individual model in each province by sex. 15 years of data for each province were held back, and the remaining data were used to estimate the parameters of each model. 15 years was the maximum duration that would still allow sufficient data to estimate model parameters. Projection bias was calculated as the difference between projected and withheld life expectancy. Second, the model weight was calculated. Individual models with larger projection biases were assigned smaller weights. In particular, each model was assigned a weight of exp(–|Projection bias|); the model weights were normalised to sum to 1. Model weights are shown in the appendix (p 8). Finally, all available data for each province and sex were used to project life expectancy in 2035. A number of simulations from the posterior distribution of age-specific mortality under each individual model were probabilistic combinations according to the model weight calculated following the above steps, and the simulations were pooled to obtain the posterior distribution of age-specific mortality under the BMA approach, which was then used to calculate life expectancy. Life table methods were used to calculate life expectancy for each age group. The Kannisto-Thatcher method was used to expand the terminal age group (85 years and older) of the life table.[10]

To quantify the uncertainty around all estimates, we generated 1000 simulations from the posterior distribution. The final point estimates were derived from the median of these simulations, and the 95% credible intervals (95% CrI) were derived from the 2·5th and 97·5th percentiles.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

The life expectancy at birth in mainland China was 77·7 years (95% CrI 77·5–77·7) in 2019 (81·0 years

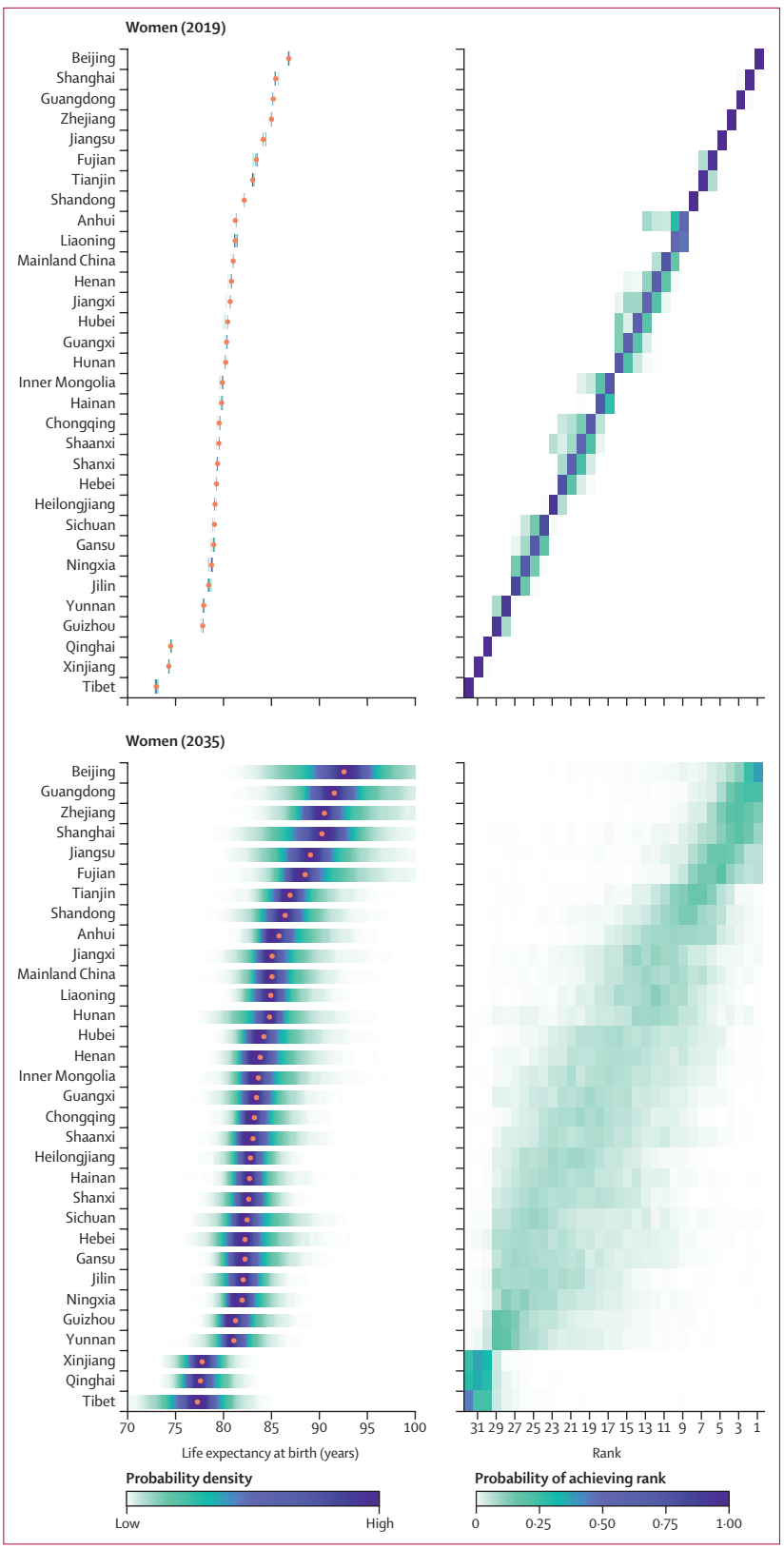
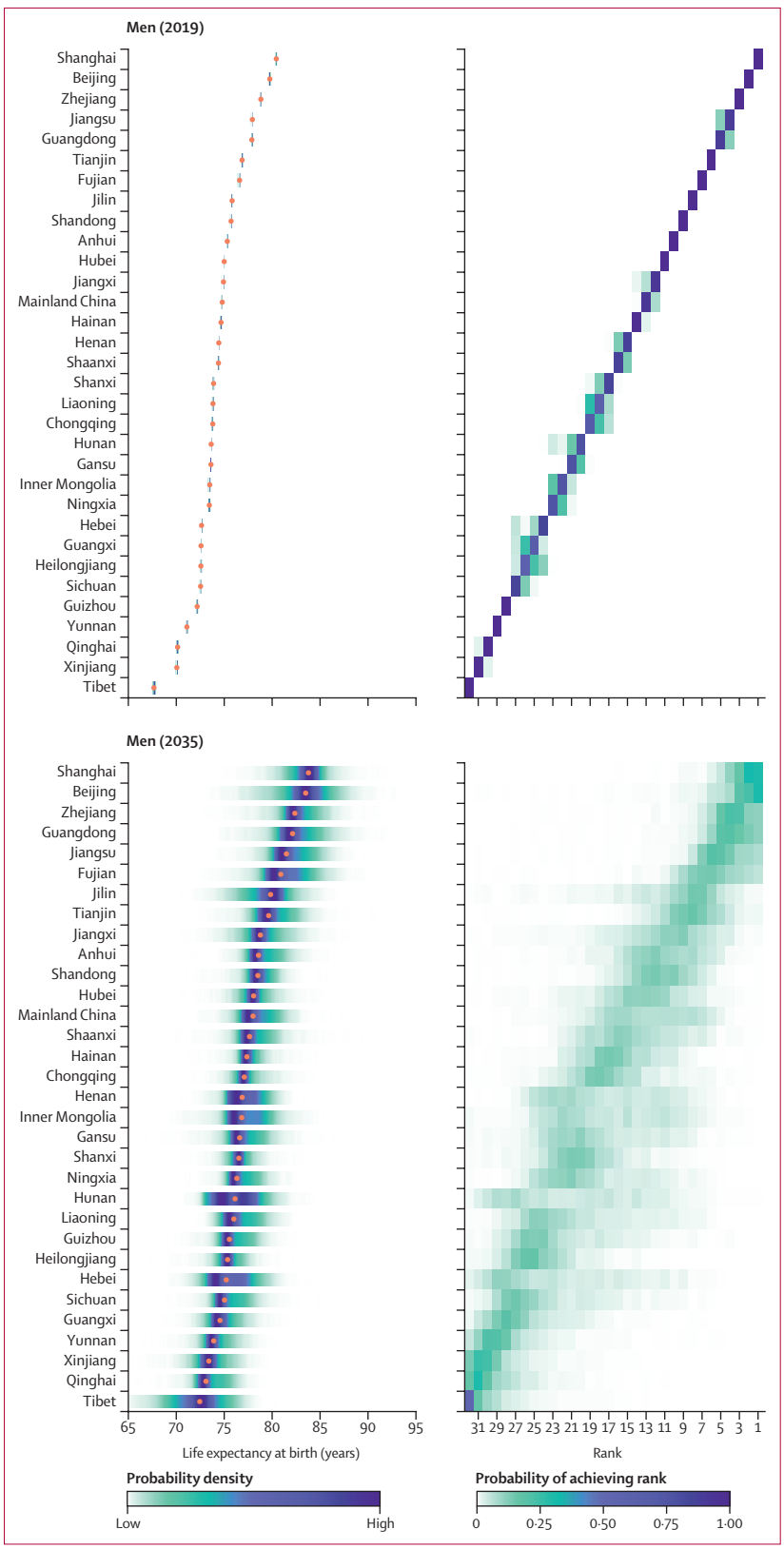


Figure 2: **Projected life expectancy of women in 2035 *vs* 2019 for 31 provinces in mainland China**

Left: Distribution of life expectancy and its median value. Orange dots show the median life expectancy. Right: Probability distribution for each province's rank. Provinces are ordered vertically by the median life expectancy from the largest (at the top) to the smallest (at the bottom).



[80·8–81·0] for women and 74·8 years [74·7–74·8] for men). Life expectancy is expected to rise steadily and reach 81·3 years (95% CrI 79·2–85·0) by 2035 (85·1 years [82·1–89·8] for women and 78·1 years [76·0–81·6] for men). Our projections indicate a 96% probability that life expectancy at birth in mainland China in 2030 will reach 79 years (the goal of the Healthy China 2030 Plan) and a 93% probability that life expectancy at birth will surpass 80 years in 2035 (the goal of the 14th Five-Year National Health Plan; figure 1).

Figures 2 and 3 show the distributions of projected life expectancy at birth for women and men and the ranked distribution for each unit. Women in Beijing are projected to have the highest female life expectancy in 2035 (with a 38% probability), and a 26% probability of being in second place. According to our projections, there is an 81% probability that life expectancy at birth among women in Beijing in 2035 will be longer than 90 years, followed by women in Guangdong, Zhejiang, and Shanghai, with probabilities of 78%, 62%, and 54%, respectively, of breaking the 90-year barrier (figure 2).

Men in Shanghai are projected to have the highest life expectancy at birth, with a 98% probability that life expectancy will surpass 80 years in 2035 and a 77% probability of life expectancy surpassing 83 years (the highest provincial life expectancy in mainland China in 2019). Men in Beijing, Zhejiang, Guangdong, Jiangsu, and Fujian have a probability of more than 50% for surpassing a life expectancy of 80 years (figure 3). The projected life expectancy at birth for each province in mainland China is shown in the appendix (pp 9–19, 28).

Projected changes in life expectancy at birth from 2019 to 2035 are shown in the appendix (p 20). Our projections indicate that life expectancy will increase in all provinces of mainland China, with a probability of at least 94% for women and 95% for men. The provinces with the largest projected gains in women's life expectancy are Guangdong, Beijing, Zhejiang, and Fujian, with at least a 53% probability of an increase of more than 5 years and median increases of 6·3, 5·7, 5·5, and 5·1 years, respectively. Men in Tibet, Fujian, Guangdong, and Jilin are projected to have the largest gains in life expectancy, with at least a 53% probability of an increase of more than 4 years, and median increases of 4·9, 4·4, 4·3, and 4·1 years, respectively.

Figure 4 shows the projected changes in life expectancy (from 2019 to 2035) versus the life expectancy in 2019 by sex. Most provinces with a higher life expectancy for women (compared with the average life expectancy of mainland China) in 2019 are projected to have higher

Figure 3: **Projected life expectancy of men in 2035 *vs* 2019 for 31 provinces in mainland China**
Left: Distribution of life expectancy and its median value. Orange dots show the median life expectancy. Right: Probability distribution for each province's rank. Provinces are ordered vertically by the median life expectancy from the largest (at the top) to the smallest (at the bottom).

gains in life expectancy. The life expectancy of some western provinces with a lower life expectancy for men is projected to increase rapidly (eg, Tibet, Guizhou, Inner Mongolia, Xinjiang, Chongqing, and Shaanxi).

In 2019, life expectancy at age 65 years was highest for women in Beijing, at 23·9 years (95% CrI 23·9–24·0). By 2035, six of the provinces are projected to surpass 25 years (>50% probability; appendix p 21). The life expectancy at 65 years for men in four provinces is projected to surpass 20 years (>50% probability), a level that was not achieved in any province in 2019 for men (appendix p 22). The projected life expectancy at 65 years for each province in mainland China is shown in the appendix (p 29).

The gap difference in life expectancy between female and male is projected to increase from 6·2 years in 2019 to 7·0 years in 2035 in mainland China. For each province, Guangxi, Liaoning, Guangdong, and Beijing had the largest sex differences in life expectancy in 2019, with 7·7, 7·4, 7·3, and 7·1 years, respectively. Jilin had the lowest at 2·7 years. Our projections indicate that the sex differences will increase by 2035 in all provinces except Tibet, Jilin, and Guizhou, where the life expectancy of men is projected to increase at a faster pace compared with women (appendix p 23).

In most provinces, more than half of the projected gains in life expectancy at birth for women are due to improvements in longevity among older individuals (aged ≥65 years), except in Xinjiang, Tibet, Qinghai, Yunnan, and Guizhou. In Qinghai, Yunnan, and Guizhou, more than one-third of the projected increase in life expectancy at birth in women is due to improvement in longevity among older individuals. In Xinjiang and Tibet, the projected gains in life expectancy at birth for women are mainly due to younger (Xinjiang) and middle-aged individuals (Tibet). In most provinces, more than one-third of projected gains in life expectancy at birth for men are due to enhanced longevity in older individuals, except in Xinjiang, Qinghai, and Tibet. In those provinces, the projected gains in life expectancy at birth for men are mainly due to younger individuals (figure 5).

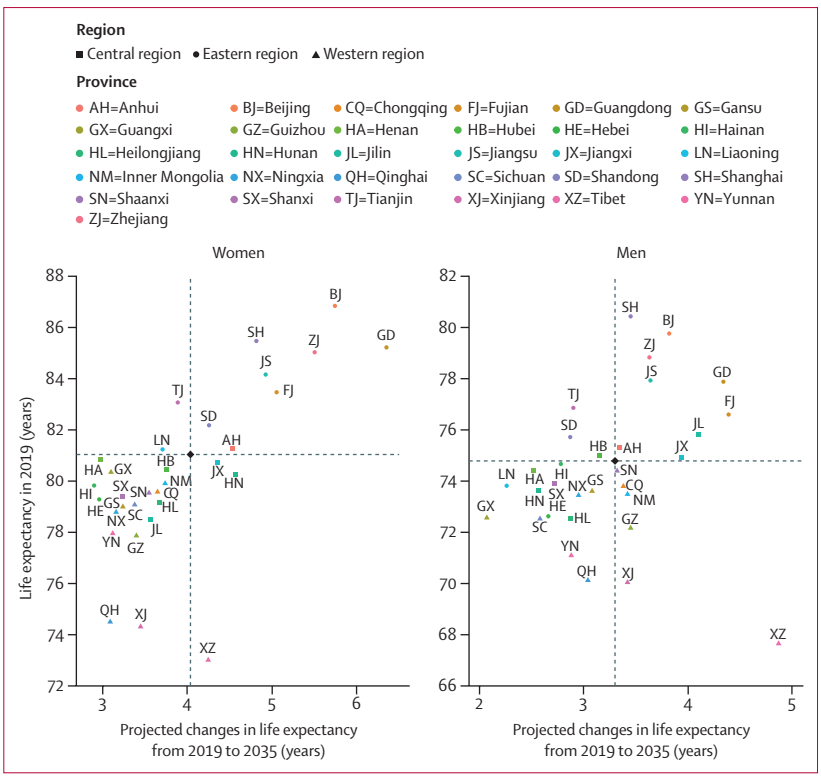


Figure 4: **Projected changes in life expectancy from 2019 to 2035 *vs* life expectancy in 2019 for 31 provinces in mainland China**

The black diamond dot at the intersection of the dashed lines indicates mainland China. Upper-left: provinces with a higher life expectancy (compared with mainland China in 2019) but lower projected gains (from 2019 to 2035). Upper-right: provinces with a higher life expectancy (compared with mainland China in 2019) and higher projected gains (from 2019 to 2035). Lower-left: provinces with a lower life expectancy (compared with mainland China in 2019) and lower projected gains (from 2019 to 2035). Lower-right: provinces with a lower life expectancy (compared with mainland China in 2019) but higher projected gains (from 2019 to 2035).

Discussion

Our projections indicate that there is a high probability that life expectancy will continue to increase in China, and that life expectancy in mainland China will reach 81·3 years in 2035. The increase in life expectancy is projected to be largest in Tibet for men and Guangdong for women. Most of the projected gains in life expectancy occur for older people, especially women.

Our projections for the life expectancy of both sexes and for men in mainland China are broadly similar to a previous study (80·7 years for both sexes)[11] and those of the UN (81·1 years for both sexes and 78·9 years for men),[8] but ours are higher for women than the UN's projections (83·5 years for women).[8] This discrepancy might be partly explained by different methodologies. The method used by the UN would make longer time period projections, but this projection might be more conservative, especially for women in China (with greater changes in the life expectancy curve trajectory), when using long-term original data (the UN used the latest seven decades). At the subnational level, women in some provinces in mainland China have a high probability of surpassing 90 years (eg, Beijing, Guangdong, Zhejiang, and Shanghai), which was considered unattainable at the beginning of the 21st century by some researchers,[12] but within what most demographers would now consider possible.[1,6,13–15]

China has made tremendous progress in improving health over the past few decades.[16] Increases in life expectancy might be associated with declines in fertility and reductions in infant mortality,[17,18] and recent increases might be associated with declines in mortality from cardiovascular disease, chronic respiratory disease, and tumours,[19] although they remain the leading causes of death in China.[4] These declines in mortality might be linked to recent public health developments, such as increased public funding for health,[20] improved access to

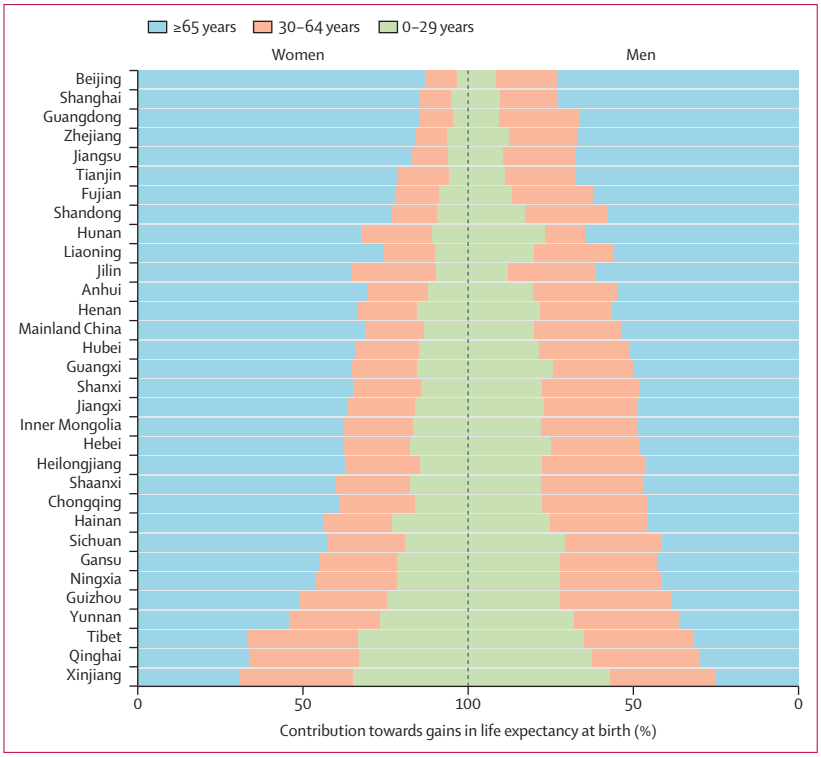


Figure 5: **Contributions of the projected decline in mortality by age group for 31 provinces in China**

health care and decreased health inequality,[21] increased education level,[22] and improvements in nutritional status.[23,24]

This study indicated that life expectancy varies between provinces in mainland China. There are large variations in social development level and disease burden within the country.[4,25] The social development level of some provinces is similar to that of high-income countries, and the life expectancy has recently exceeded that of South Korea and the USA.[25] However, some provinces have characteristics of low-income countries, with a high burden of infectious diseases and neonatal mortality, as well as high levels of cerebrovascular disease, gastric cancer, and road injuries.[25] In addition, the urbanisation rate also varies among provinces (with some western provinces having lower rates of urbanisation), and urban populations have higher income and access to better health services and education. These disparities have led to regional differences in life expectancy in the past. Reassuringly, life expectancy is catching up quickly in some western provinces and is expected to continue to increase in the future (eg, the life expectancy of men in Tibet is expected to increase substantially). These increases could help reduce inequalities in life expectancy across regions. It is expected that life expectancy in some wealthier eastern provinces will continue to lead countrywide (eg, Beijing and Shanghai). These provinces have better medical resources,[26] and the burden of disease is also lower than in other provinces.[4] The projected gap in life expectancy between men and women in most provinces is increasing, which is consistent with historical data.[27] The current sex differences in life expectancy are mainly due to differences in deaths from non-communicable diseases (respiratory diseases and circulatory diseases), cancer (eg, lung cancer, liver cancer, and gastric cancer), and external causes (eg, traffic accidents and suicide).[25,27] Risk factors for these disorders (eg, smoking[28]) trended differently among men and women in China.[29]

Increases in life expectancy will require health-care and social service resources. Moreover, non-healthy life expectancy (ie, years lived with disability) might also increase because the improvement in healthy life expectancy is not parallel with life expectancy (healthy life expectancy is increasing at a slower speed than life expectancy in China),[30] which implies the need for approaches throughout the life course to prevent or delay the onset of chronic diseases to promote healthy longevity.[31] In addition, some effective health education or economic measures should be taken to promote healthy ageing—eg, reducing the use of tobacco and alcohol, improving diet and physical activity, and controlling obesity. Long-term care for an increasing number of older adults affected by multiple conditions and mobility limitations also needs to be considered.[32] Integrated care in community settings or even at home should be considered,[33] along with appropriate changes to the built environment and transportation services.[34] Differences in life expectancy between regions can help prioritisation of resources and measures—in particular if combined with regions' demographics (appendix p 24) and population comorbidities (appendix p 25), and previous research.[4] It is important to differentiate regional strategies and reduce the life expectancy gap between regions.[35] Crucially, an increase in life expectancy will increase pressure on spending on social security and pensions, which also means that advance planning is needed.[36]

An important strength of this study is that we integrated the largest epidemiological and demographic mortality data for mainland China and its provinces and used the BMA framework to integrate the prediction results of multiple models, which is more reliable than the prediction of a single model.[6]

This study is also subject to various limitations. First, similar to other prediction analyses, unexpected events in the health system and society can affect the outcomes of predictions. The occurrence of COVID-19 in late 2019 has had an impact on life expectancy in some countries.[37] Increased COVID-19 vaccination and infection-acquired immunity should limit the impact of the pandemic on life expectancy.[38,39] If we use the 1918–20 influenza pandemic as a reference, mortality and life expectancy might not be substantially affected in the long run.[40] Second, although we compiled the most comprehensive data sources, some original data sources (eg, the Disease Surveillance Point system) cover fewer districts and

countries in poorer and remote provinces at early stages and might affect the precision of our estimates. We gave greater weight to the data in recent years in the prediction process, which might reduce the prediction bias to some extent. Third, although our life expectancy projections captured the uncertainty in model selection and improved the predictive validity, the projection model did not include health risk factors (eg, smoking), which might overlook the impact of important health scenarios. To test the performance of our projection, we extended it to 2040 and compared our projection with that of a notable large-scale study that included health risk factors.[41] Our life expectancy projections for mainland China were broadly similar to those of the other study. Fourth, we did not provide estimates of life expectancy for rural and urban areas separately. Considering the difference in health burden between these areas, future work should extend to rural and urban areas.

In conclusion, there is a high probability that life expectancy will continue to increase in China and that the national goals of improving life expectancy will be achieved. By 2035, the life expectancy of women in some provinces might reach 90 years. However, life expectancy remains associated with location, with more industrialised and wealthier eastern provinces having a higher life expectancy than more rural and poorer western provinces. Considering these differences, it is necessary to formulate and implement targeted measures to support the populations.

Contributors

RB initially conceived the research idea, designed the study, performed data management and analysis, and drafted the manuscript. YL performed data collection and management, and drafted the manuscript. MZ directed the study, and has responsibility for the integrity of the data and the accuracy of the data analysis. RB, YL, LZ, WD, ZB, and MZ critically revised the manuscript. All authors read and approved the final manuscript. RB, YL, and MZ accessed and verified the data. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The data are not publicly available due to data sharing regulations established by China CDC, but could be made available from the corresponding authors on reasonable request.

Acknowledgments

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