Provincial mortality disparities in China: A comparative study based on 2010 census

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Abstract: This paper examined provincial mortality patterns and levels in China's 31 provinces mainly based on the data from the 2010 census. Through a model-based clustering analysis and the comparison with model life tables, age patterns of provincial mortality in 2010 can be divided into 10 patterns and present geographical features and male and female patterns may not be the same in a certain province. Female advantage in mortality over male mainly appears in adulthood years, but in childhood and old ages, such advantage become weakened. Life expectancy still shows a downward trend from eastern coastal areas to western inland areas, and 5 groups have been distinguished based on life expectancy and sex difference in each province. The analysis of decomposing sexual and provincial difference in life expectancy at birth elucidates sex differences are mainly contributed by old ages while childhood is less significant. Differences among provinces are primarily caused by old-age and child mortality differential. The calculation of life table entropy shows in 2010 deaths in most of provinces have reach the third stage of mortality transition and female has a faster mortality transition progress than male.

Keywords: China; provincial mortality; life expectancy; age pattern of mortality; life table entropy

1 Introduction

The mortality of China's population plays a vital role in the analysis of population mortality in the world. In the year of 2018 the population in China mainland has reached 1.428 billion, accounting for 18.7% of the global population (United Nations 2019). Due to the implement of One-child policy, the demographic transition has completed from the stage of "high fertility – low mortality" to "low fertility – low mortality" within 10 years in China mainland after the 1980s (Hussain 2002, McNicoll 2006); during the period between 1980 and 2010, CDR stayed in around 6.34‰ ~ 7.11‰ while CBR has declined from 18.21‰ to 11.90‰ (National Bureau of Statistics of China 2018) and *TFR* from 2.52 to 1.62 (United Nations 2019). Due to the improving quantity and quality of living and medical conditions, plus poverty alleviation program, economic development, disease prevention and treatment progress, and the re-establishment of the nationwide medical care system, China mainland has experienced great improvement in mortality (Zhao, Chen and Jin 2016). Life expectancy at birth increased significantly from an average of 60 years in the period of 1964−1982 to nearly 70 years between 1990 and 2000, and further, reached above 71 years by 2000 (Banister and Hill 2004). However, because of unequal social developments in terms of society, economy, bring about health care inequalities (Zhao 2006), there exists significant heterogeneity in mortality of different regions. In 2010 income per capita of Beijing, Zhejiang and

Shanghai was $6253.4, $5710.7 and $6767.2 respectively, while Yunnan, Tibet and Qinghai was $2956.7, $2824.1, and $2617.1(NOTE 1) (National Bureau of Statistics of China 2011): the first three areas already belong to upper-middle-income regions, and the latter three provinces are lower-middle-income regions according to 2010 regional classification based on income per capita by World Bank (2018). The corresponding is that life expectancy at birth has already exceeded 80 years in Beijing and Shanghai, whereas it was still lower than 70 years in Yunnan, Tibet and Qinghai; life expectancy at birth in eastern and coastal regions was generally higher than that in northwest and inland regions (National Bureau of Statistics of China 2017).

Population census is the procedure of systematically collecting information about the members of a given population. Unlike other developing countries, the central government of China has been conducting relative comprehensive censuses almost every 10 years since 1980 and has gradually established vital registration and disease surveillance system (Yang, Hu, Rao et al. 2005, Wu and He 2015), making it feasible to analyse the age pattern and trend of mortality in China mainland. The 6th census in 2010 of China (NOTE 2) is the latest census offering the demographic information of 31 provinces for population study. A comprehensive research through such data on the disparity in mortality and the causes behind them is conducive to deeply exploring China's demographic patterns and trends. Besides, mortality pattern analysis always provides the theoretical foundation for the formulation of most public services polices such as social security and long-term care, precise analysis of provincial age pattern of mortality contributes to forming appropriate systems for provinces with various social development, especially for China facing emerging aging issue.

However, unfortunately, so far most studies concentrated on national analysis (Cai 2013, Zhao, Chen et al. 2016, Lu, Peng and Chen 2019), whereas few pay attention to the provincial pattern and level. The main reason for this awkward situation may be data quality. Undoubtedly, the foundation of provincial mortality analysis also lies on the relative accurate mortality data, but the existence of infant and old-age mortality underestimate in 2010 census (Hu, Wang and Yu 2015, Gu, Huang, Andreev et al. 2016, Li and Mi 2019) impact negatively on the effectiveness. And related materials essential to correct national mortality are more abundant than province-specific counterparts. Although the underestimate problem also existed in 1990 and 2000 census (Zhang and Li 1997, Li and Sun 2003, Banister and Hill 2004), the deficiency in 2010 census is very prominent compared to previous two censuses. Therefore, this paper first corrected the underestimate existing in provincial mortality data from the 2010 census, and then, based on this, intends to provide a general overview about age pattern and level of 31 provinces' mortality in China mainland. All the calculation in this paper were made by R language (R Core Team 2019).

2 Data

The data mainly came from two sources: First, we sorted out the age-specific mortality data of 31 provinces tabulated on China's 2010 population census, covering from age 0 to 100 and over. Second, we collected under-5 mortality in provinces from China subnational Millennium Development Goal 4 (MDG 4) (Institute for Health Metrics and Evaluation 2015) for correcting infant mortality underestimate in 2010 census. This dataset provides the province-specific under-5 mortality estimates for the period 1990 to 2013, which is derived from China's censuses since 1982, the 1‰ Survey on Fertility and Birth Control, the 1‰ Annual Survey on Population Change, the 1% Survey on Population Change, the Maternal and Child Health Surveillance (MCHS) and the Disease Surveillance Point System. All the sources have been examined through completeness estimates and this dataset has great consistent with

China's data in Global Burden of Disease Study (GBD) 2013 Neonatal, Infant, and Under-5 Mortality(Wang, Liddell, Coates et al. 2014) in terms of estimate method and the aggregate national value derived from province-specific ones (Wang, Li, Zhou et al. 2016), so we considered the quality of this dataset is superior to census.

The correction of mortality data is divided into three parts: correction of mortality below age 5, estimating the completeness of death age 15 and above and re-calculating age-specific death rate at advanced ages, their details and subsequent life table compilation are described in Appendix I. Table 1a and 1b display the comparison of ${}_{1}m_{x}$ between census and the adjusted values. Finally, we acquired province-sex-specific abridged and complete 128 life tables.

[Figure 1a is here]

[Figure 1b is here]

3 Methodology

Age patterns of provincial mortality is one of important facets in the analysis of provincial mortality discrepancies. Albeit age patterns of mortality diversify with provinces, the similarities must exist among them. We adopted Gaussian Finite Mixture Model clustering method (Fraley and Raftery 2002, Scrucca, Fop, Murphy et al. 2016) to classify age patterns of provincial mortality and analysed complete and abridged life tables respectively to guarantee the consistency of results. Before the cluster analysis, we first adjusted provincial life tables to the ones with national e_0 in order to eliminate the impact brought by life expectancy at birth on discrepancy in age patterns of mortality. We adopted (Brass 1971) model to finish this task:

$$logit\left[q\left(x\right)\right] = \alpha + \beta \cdot logit\left[q^{s}\left(x\right)\right] \tag{1}$$

where α stands for the difference between mortality levels of two life tables, and β reflects the disparity in age patterns. For two identical life tables, α=0 and β=1. We took provincial age-specific death probability as standard $q^s(x)$, let β=1 and calculated α by dichotomy iteration (Lu 1991), whose details is in Appendix II, to make $q(x)$ produced by Eq.(1) conform to national e_0.

The clustering steps were divided into coarse, fine clustering and graphical verification to reduce randomness. The coarse clustering fixed $q^s(x)$ on national age-specific death probability and substituted adjusted provincial ones described above to $q(x)$ in Eq.(1), calculated male and female βs (taking the mean of values from abridged and complete life tables as the used value), then performed the model-based clustering on the 31×2 matrix. Such step elucidated the age patterns of provincial mortality can be classified into at least 7 patterns.

The fine clustering operationalized the age pattern of mortality in each adjusted provincial life table as the vector of $logit[q(x)]$. We first reduced the dimensionality of the data using Singular Value Decomposition (SVD) of the empirical schedules of $logit[q(x)]$:

$$\begin{aligned} \mathbf{Y}_{m\times n} &= \mathbf{U}_{m\times m}\mathbf{\Sigma}_{m\times n}\mathbf{V}^{T}_{n\times n} \\ \hat{\mathbf{Y}}_{m\times k} &= \mathbf{Y}_{m\times n}\mathbf{V}_{n\times k} \end{aligned} \tag{2}$$

Through Eq.(2) the data matrix $\mathbf{Y}$ with n column dimension can be reduced to $\hat{\mathbf{Y}}$ with k column ($k<n$). In order to maintain congruence between male and female schedules, we bind the male and female schedules and perform the SVD on the resulting 31×42 abridged matrix and 31×200 complete matrix. The k is confirmed by "the total deviation

from mean" (TDM), the sum of the distances between each $logit[q(x)]$ vector and the mean of all $logit[q(x)]$ vectors in the cluster to which it belongs. Lower TDM values imply less variation among $logit[q(x)]$ schedules in each cluster and the optimal clustering owns the minimum TDM value. We conducted the clustering on the dimension-reduced dataset with k varying from 2 to 10 and chose the results with the smallest TDM.

Theoretically, the clustering results by abridged and complete schedules should be identical with each other. In practice, difference exists in the outcomes from the two. Thus, we selected the provinces classified into the same pattern in abridged and complete scenarios and re-adjusted the outcomes by minimizing the distance between provincial vector and the mean vector of each pattern, and the left provinces are reclassified through the same procedure. The provinces that cannot be classified into the same pattern by the procedure above are taken as solo patterns. The graphical verification took the ratios $R(x)={}_nq_x/{}_nq_x^c$ as the index, where ${}_nq_x$ is from the given adjusted provincial life table with national e_0 and ${}_nq_x^c$ from national life table. The $R(x)$ values are then plotted against age for each life table and the plots are arranged based on similarity of curves. The clusters produced by this method are essentially the same with previous steps.

Another way of studying age patterns of provincial mortality is to compare with model life tables. We used three model life tables—Coale-Demeny(Coale, Demeny and Vaughan 1983), United Nations (1982) and China Classified (Jiang, Wang, Luo et al. 1988) model life tables (NOTE 3)—and compared the degree of resemblance between these and provincial mortality schedules through the similarity index (United Nations, 2013; Zhao, 2003), such computation were made for males and females separately. The smaller index figure is, the better the fit between a given model pattern and the mortality schedule of the population studied is, and a value of zero means a perfect fit.

In addition to age patterns of mortality, life expectancy at birth is another indicator of regional discrepancy in mortality. The disparity in life expectancy at birth between two populations comes from aggregate effect of variable difference at each age. One common approach is to decompose the difference in life expectancy at birth into age-specific difference, which is helpful to estimate the contributions of each age to the overall difference. So far, several general decomposition methods like Kitagawa (1955) method, Gupta (1991) method and stepwise replacement (Andreev, Shkolnikov and Begun 2002), Horiuchi, Wilmoth and Pletcher (2008) method have been developed. In this paper we took advantage of Horiuchi et.al method to decompose the differences in life expectancy at birth because this method is superior to other methods in a fewer practical limitations.

How is life expectancy at birth affected by the variation of age-specific mortality? Such relationship can be measured by the quantity H (Keyfitz and Caswell 2005), or life table entropy (Demetrius 1976), which captures increasingly rectangularization of the survival curve when mortality declining and increasing proportion of death happening at old ages. Entropy H measures the impact of the change in age-specific mortality on life expectancy at birth (Demetrius 1979, Goldman and Lord 1986), giving the percentage change in life expectancy at birth produced by a reduction of one percent in the force of mortality at all ages. A high H implies that deaths happen widely in entire age range, and a low entropy means deaths are concentrated in a narrow age range (Wilmoth and Horiuchi 1999, Glei and Horiuchi 2007). The rule of thumb is that when entropy is higher than 0.20, age distribution of deaths disperses across the life span with a relatively large proportion of deaths occurring in young and adult ages.

The definition of H is minus the mean value of $\ln l(x)$ weighted by $l(x)$ (Keyfitz and

Caswell 2005):

$$H = -\int_0^{\omega} l(x)\ln l(x)dx \Big/ \int_0^{\omega} l(x)\,dx \tag{3}$$

Goldman and Lord (1986) gave another interpretation of H as the average years of future life lost by the death, approximately:

$$H = \int_0^{\omega} d_x e_x dx \Big/ \int_0^{\omega} l_x dx = \int_0^{\omega} d_x e_x dx \Big/ e_0 \tag{4}$$

4 Results

4.1 *Discrepancies in age patterns of provincial mortality*

The age patterns of province-specific mortality can be classified into 10 groups (Figure 3a to 3j), and majority provinces in the same group are geographically adjacent (Figure 2), indicating that distribution of mortality patterns has distinct regional characteristics. The first group, called Central-East group, contains Anhui, Fujian, Hubei, Hunan, Liaoning, Shandong, Jiangxi, whose characteristics are higher child mortality aged 1−4 and the mortality of other age groups similar to national level. The second group includes Guangdong, Jiangsu and Zhejiang, the provinces with relative advanced GDP per capita and called Developed group, having the features of lower mortality in infant and young adult years and mortality aged 45 and over close to national average. The third group is First-tier pattern because the municipalities in this group are most developed in China, it includes Beijing, Shanghai and Tianjin with the features of significantly low mortality in adult and child under age 10 and higher mortality age 65 and above, perhaps reflecting superior living and nutrition standard, the immigration of robust adult labour force and relative high level of tumour and circulatory system disease at old ages.

The fourth, fifth and tenth groups of Gansu-Hainan, Hebei and Shanxi, Tibet-Xinjiang are, as their names show, consist of two provinces. The Gansu-Hainan group is characterized by relative high child mortality under age 5, from which it indicates similar age patterns of mortality would occur in even geographically non-adjacent regions. The feature of Hebei-Shanxi group shows increasingly low mortality from age 5 to 59 and higher mortality above age 60. The Tibet-Xinjiang group is characterized by decreasingly high mortality between age 0 to 44, indicating high mortality level in infancy, childhood and adult years, but apparently lower mortality at older ages above 70 and representing a downward trend. Besides, female mortality at reproductive ages is apparently higher than national level, which probably is related to high incidence of maternal death.

Ningxia and Qinghai are two provinces constituting the sixth and eighth groups respectively. The pattern of the Ningxia group shows a N-shape curve, signifying high mortality during young adult years but lower mortality at older adult ages, as well as little higher mortality age 80 and over. The Qinghai group is characterized by significantly high mortality during childhood and adult years, and relative lower mortality at old age 70 and over.

The provinces in the seventh group, containing Heilongjiang, Henan, Jilin, Nei Mongol and Shaanxi, mainly locates in the northeast region of China, so it is call Northeast group. The characteristics of this pattern is similar to Hebei-Shanxi group, but have lower mortality during childhood and young adult ages, relative higher mortality between age 40 to 74 as well as lower mortality over age 80. The ninth group, labelled Southwest pattern because both provinces included (Chongqing, Guangxi, Guizhou, Sichuan, Yunnan) locate in the southwest region of China, is characterized by

M-shape pattern curve before old ages, reflecting high mortality at child and adult age, may implying the emigration of healthy young adults as floating labour force.

[Figure 2 is here]

[Figure 3a−3j is here]

Through the comparison with model life tables(Table 1a and 1b), West pattern in Coale-Demeny model life table, General pattern in United Nations model life table and Southwest pattern in China Classified model life table are the three patterns that majority of provincial mortality patterns resemble, and in some provinces male and female patterns are not similar to the same model life table pattern. The typical case is the provinces in Southwest group: male pattern is similar to Latin American pattern while female pattern is to General pattern, and totally this group is close to North pattern. Additionally, the indices of the province with low life expectancy at birth generally tends to be greater than those with high life expectancy at birth, which may be related to the following reasons: The first one is data quality. Although the death rate in census was adjusted, such adjustment is in a wide age group. A precise adjustment for narrower age groups is hard to be finished due to information deficiency, which means the relative error between each age group is not fixed. The provinces with higher e0 mainly locate in eastern areas while the provinces with lower e0 are in western areas. Overall, the mortality registration and surveillance system in the eastern areas are more improved than western areas (Yang, Hu, Rao et al. 2005), making death data of eastern have better quality; Next, the model life tables with high mortality levels are mainly derived from extrapolation rather than empirical mortality data when being constructed, leading to discrepancies between the model life tables and mortality patterns recorded in real populations with high mortality (Zhao 2007). Alternatively, the high value of the index might be caused by variations in mortality at different age groups. Provinces with high e_0 are always developed, while the counterparts with low e_0 belong to developing area. Developmental disparities bring about swift or sluggish progress of mortality decline in provinces. Developed provinces has reached low mortality level, slow and steady mortality decline possibly have taken place in most of the ages, causing a small similarity index; However, mortality decline may be underway in developing provinces with high mortality level, and mortality declines with the same magnitude may not happen simultaneously at all ages (Zhao and Kinfu 2005). Such difference tends to increase the value of similarity index.

[Table 1a is here]

[Table 1b is here]

What should be mentioned here is the comparison with China Classified model life table, which was constructed based on China’s 1982 census and the pattern division of which is on the basis of the provincial mortality in 1981 (Table 2). It can be found in Table 1a and 1b that provincial mortality patterns in 2010 have evolved during almost the past 30 years. The most significant example is Xinjiang, whose mortality pattern of Xinjiang was classified as a sole pattern in 1981, but in 2010 the closest mortality pattern to Xinjiang is Southwest pattern. Additionally, the pattern to which Jiangsu, Shandong and Zhejiang belonged in 1981 is Middle and east China pattern, it has transited into North China pattern in 2010 and so forth. For some provinces, male and female patterns have changed towards different direction, e.g. in 2010 male mortality pattern of Shaanxi still fixes in Southwest pattern, while female pattern has turned into North China pattern; male pattern of Hubei has changed into Southwest pattern but female counterpart into North China pattern. The results above demonstrate that age pattern of mortality would experience transitions over time instead of conforming to a single mortality pattern, as well as the transitions in male and female pattern would not synchronize or be identical with each other.

[Table 2 is here]

4.2 Sex differential in mortality

Sex differentials in mortality are another imperative issue in mortality analysis, which can be examined through computing the sex ratio of age-specific death probability. The ratio greater than one represents male mortality is higher than female mortality, otherwise male mortality equals or is lower than female mortality. These results are presented in Figure 4.

The common feature of sex differential in mortality for each province is that female mortality advantage at adult ages is more significant except for childhood and old years. Mortality difference among male and female infant is small because of the son preference in China, even in some provinces like Jiangxi, Guangdong and Gansu female infant might experience a relatively higher mortality, which may be related to human intervention such as negligence of daughter in these provinces. Yet this situation has eased in Shanghai, Beijing and Tianjin as the sex ratio of death probability in infant and childhood is larger than 1. Further observation elucidates that differential patterns in adult mortality emerge as basically four categories: First, sex differential in mortality have apparent fluctuation and life expectancy at birth of the provinces with such pattern is beyond 80 years e.g. Shanghai, Beijing, Tianjin; The second category is featured by relative stable sex differential in adult mortality, female advantage in mortality over male seems to be unchanged in adulthood e.g. Guangdong and Chongqing. Their life expectancy at birth generally locates between 77 to 80 years; The third category is featured by a peak in adult ages although the width varies with provinces, and the age of peak ranges from 20 to 50 years. Most of province belong to this situation. The final category is that sex differential is not significant compared with others, e.g. sex ratio of death probability in Qinghai and Tibet are close to one, and life expectancy at birth of these provinces are lower than 73 years.

[Figure 4 is here]

4.3 Comparison of life expectancy and decomposition

In the period of 2005 to 2010, life expectancy at age 0 and 60 of Mainland China have reached 73.68 years and 18.62 years, close to developed regions and higher than the average levels of developing areas (United Nations 2019), demonstrating a great achievement China has in reducing mortality. With reference to other developing countries on the condition of similar GDP per capita, such high life expectancy of China is quite remarkable. From inner perspective, however, obvious discrepancies exist between provinces. Despite in all provinces e_0 and e_{60} go beyond 70 years and 19 years respectively (Figure 5a and 5b), the difference in e_0 between the highest values and the lowest values are 11.65 years for male and 12.28 years for female, that in e_{60} are 4.69 years for male and 6.15 years for female. In terms of regional distribution, coastal provinces, usually developed regions with higher urbanization in China, always possess higher e_0 and e_{60}, central provinces stay in the second position while e_0 and e_{60} in western provinces stays in the lowest level. Compared with the analysis on 1982 census(Hao, Arriaga and Banister 1988), the differences between the highest e_0 and the lowest decrease by 1.7 years for male and 4.7 years for female, showing that the reform and open policy introduced by central government in 1978 benefits most provinces in all aspects of social life. Whereas it cannot be denied that minor variation in the overall distribution has happen during the almost 30 years, an unbalance tendency still exists distinctly in regional development. From another point of view, the figures manifest that many provinces in China also have great potential for further decline in mortality.

[Figure 5a is here]

[Figure 5b is here]

In a whole, provincial total life expectancy at birth and its sexual gap disperse more broadly than life expectancy at age 60 (Figure 6). The largest sexual gaps in e_0 and e_{60} appear in Guangxi (6.88 years and 4.31 years respectively). The lowest sexual gap in e_0 happens in Tianjin with 3.06 years, and the counterpart in e_{60} appears in Ningxia with 1.86 years. We took national value as the central point and divided each figure into four quadrants. Inner circle refers to the difference with the national total life expectancy and sexual gap less than 1 year. Therefore, all provinces can be divided in to five groups:

Group A. Inner circle: total life expectancy and sexual gap close to the national average.

Group B. The first quadrant outside circle (Guangxi, Hainan): high life expectancy but significant sexual gap.

Group C. The second quadrant outside circle (Yunnan, Guizhou, Jiangxi, Tibet): life expectancy lower than national average and apparent sexual gap.

Group D. The third quadrant outside circle (Hebei, Gansu, Ningxia, Qinghai, Shaanxi, Shanxi): life expectancy lower than national average and narrow sexual gap.

Group E. The fourth quadrant outside circle (Beijing, Jilin, Tianjin, Zhejiang): long life expectancy with small sexual gap.

[Figure 6 is here]

We decompose the difference in e_0 from sexual and provincial aspects. The decomposition of sexual difference of life expectancy at birth illustrates that albeit life expectancy at birth varies with provinces the result remains basically similar (Figure 7): the most positive contributions to sexual gap in e_0 are made by old ages, 55% of sexual difference on average is brought by mortality differential at ages 60 to 89. Childhood ages contribute less to the whole difference. The exception is Xinjiang where the most contribution is made by infancy group. Another outstanding phenomenon is apparent negative contribution from infant mortality in the provinces in Group B and C, implying the impact from old-age mortality on sexual difference in life expectancy at birth in these provinces is more significant than other provinces.

After decomposing the difference in life expectancy at birth between every two provinces, we found that for most of provinces, the difference in e_0 of the province and others shows similar age-specific contribution patterns, which is mainly from child or old-age mortality. A typical example is Shanghai vs Hebei (Figure 8). The e_0 difference between these two provinces is 6.81 years for male and 6.37 years for female, which is contributed by 0.65 and 0.71 years from child under age 5, 3.79 and 4.32 from ages 60 to 89, and the contributions of others age group stay around 0.03 to 0.3 years. But there still exist some exceptions, we decomposed the difference in e_0 between Hainan and others and found that the contributions from infancy and old ages have opposite direction such as Hainan vs Shanxi. The difference in infant mortality would narrows the gap by 0.49 years in male, while the effect of ages 70 to 89 enlarge the gap by 2.57 years. And increase appears in adulthood proportion in the differences between Guizhou, Qinghai and other provinces. Adult mortality discrepancy between Zhejiang and Guizhou causes differences of 3.1 years for male and 1.53 years for female, accounting for 53.3% and 32.3% respectively in total; the figures for Fujian vs Qinghai are 2.21 years for male and 2.38 for female, accounting for 42.5% and 37.3%, while the figures for other provinces is around 10%. The effects of advanced age groups in Tibet and Xinjiang is negative to the total difference, e.g. the comparison Hubei with Xinjiang reveals that the discrepancy of mortality in age 80 and over narrows the total gap by almost 1 year for male and 1.17 years for female, while for Ningxia with Tibet the values are 0.59 years for male and 1.40 years for female.

[Figure 7 is here]

[Figure 8 is here]

4.4 The effect of mortality variations on life expectancy at birth

Life table entropy varies broadly across the provinces (Table 3). Although the entropy in most of the provinces is less than 0.2, the negative correlation between entropy and life expectancy at birth is obvious, illustrating two points: First, potential decline rate of e_0 in the province with lower e_0 is faster than the province with higher e_0. In 2010, the H in Shanghai was 0.124 for male and 0.106 for female, which means that 1% reduction in the force of mortality at all ages increased life expectancy at birth by 0.12% for male and 0.11% for female; in Guizhou, this increase was about by 0.20% for male and 0.16% for female. Second, most of the provinces in 2010 have reached the third stage of mortality transition. The entropy is also an indicator of the stage of mortality transition (Chaurasia 2010). The value of entropy in most of the provinces lower than 0.2 demonstrates that most of deaths in these provinces happens in old ages. Mortality transition has at least three stages (Omran 2005): The first stage comprises high and fluctuating mortality, mainly in childhood, the main causes of death at this stage is infectious diseases, malnutrition. The second stage is characterized by progressively mortality decline, and accelerating decline rate as epidemic peaks become less frequent or disappear, in response to better living standard and nutrition, sanitation and public health measures. The third stage comprises a shift in the primary causes of mortality from infectious and concomitant diseases to degenerative disease. Based on The Nation Monitor Report of Cause of Death in 2008(Wang, Wang, Hu et al. 2009), the major causes of death for most of provinces are degenerative diseases such as cardio-cerebrovascular diseases or malignant tumor, which are always appears in old ages and the basic characteristics of the third stage of mortality transition. However, due to lack of province-age-specific cause of death data, it’s hard to confirm whether the provinces with high life expectancy at birth come into the fourth stage of mortality transition with the feature that the age distribution of death for degenerative causes are shift toward advanced ages than the third stage (Olshansky and Ault 1986), albeit these provinces have approached or exceeded 80 years. Additionally, male entropy is larger than female, implying the process of mortality transition in each sex may not be synchronous and female progress is always faster than male.

Some exceptions must be emphasized. Main causes of death in Guizhou, Ningxia, Qinghai, Tibet and Xinjiang contain injure and respiratory diseases in addition to cardio-cerebrovascular diseases, and life table entropy of these provinces are larger than or close to 0.2, which indicates that the five provinces were in the process of transition while other provinces nearly have finished. On the other hand, such evidences can also explain the contribution of old-age mortality to total difference e_0 between these provinces and others is less significant or in opposite direction.

[Table 3 is here]

5 Conclusions

Compared to other developing countries, China has made great achievement in reducing mortality. While China's socio-economic development is not comparable to developed countries, life expectancy at birth has increased dramatically during the period of 1950 to the late 1970s and reached the same level as developed countries' counterparts. China's achievement in lowering mortality, along with those in Sri Lanka, Costa and Kerala state in India, have been named as "Routes to low mortality in poor countries" (Caldwell 1986) and such achievement has been maintained in the first ten years in 20th century (Kuhn 2010). During the period of 2005 to 2010, China's life expectancy at birth has exceeded 73 years, achieving the level of upper-middle-income countries based on World Bank income groups (United Nations 2019). However, it has to pay attention to the fact that China is a populous country with unbalanced development between regions and provinces. Beyond that, numerous ethnic minorities constitute a considerable proportion in China's population and lifestyle between people in different provinces and ethnic groups displays great discrepancy. All these factors illustrate that there still exists great disparate patterns and levels in provincial mortality, although on a whole China has owed a significant progress in lowering mortality.

The intention of this article is to analyze provincial mortality disparities in China based on 2010 census by assessing levels and age patterns of provincial mortality along with analysis of sex differences and the progress of mortality transition. Through demographic measures and statistical approaches, the results indicate that age patterns of provincial mortality present geographical features, and mortality level still shows a downward trend from eastern coastal areas to western inland areas, which is close to the situation in 1981. Female has more advantage in adult mortality over male by plotting sex ratios of age-specific death probability, but in childhood and old ages, female advantage is disappearing.

The variation of mortality level causes the differences between both sex and provinces, to which contribution patterns vary across provinces. The decomposition of the difference in e_0 shows that sex differences in most of provinces are primarily caused by mortality differential in old ages, while that in childhood ages has the least contribution; provincial difference is also contributed by old-age mortality differential, as well as child mortality except for Guizhou, Ningxia, Qinghai, Tibet and Xinjiang. The possible reasons behind these phenomena is provinces in different process of mortality transition. Most of provinces have reached at least the third stage of mortality transition in which the deaths mainly happen in old ages, caused by degenerative diseases, while the exceptions mentioned above may be in the process of transition. Compared to male, more deaths in female occur in old ages, demonstrating a faster mortality transition in female than in male.

This paper still has some limitations: due to lack and inaccessibility of related data, especially province-age-specific cause of death mortality rate and mortality about migration, our analysis didn't shed light on the mechanism behind the formation of age pattern of provincial mortality and the impact of migration on mortality pattern, which have yet to be further investigated.

China's advantage in mortality over countries with similar development is an impressive fact, it also stands for China facing new challenges in further reducing mortality. The primary cause of death in China has been degenerative diseases always developing at old ages, so in future effective actions to improve the elderly's health need to be taken. In addition, inequality in medical and health services between provinces has been emerging as a prominent issue, the realization of balanced development among regions, therefore, should be the key emphasis in government's future work.

Note

1.These figures are the conversion based on exchange rate of RMB vs USD in 2015.
2. China's 2010 census excludes the data of Hong Kong SAR, Macao SAR, and Taiwan.
3. These three model life tables we used are extended version. Coale-Demeny and United Nations model life tables are extended by Population Division, United Nations. China Classified model life table are extended by Zhenghua Jiang, Hongyan Liu, Kuangshi Huang and Jiangfeng Gui in their monograph *China Regional Model life Tables* (*Abridged Life Tables Extended Version*), published by China Population Publishing Press in 2016.

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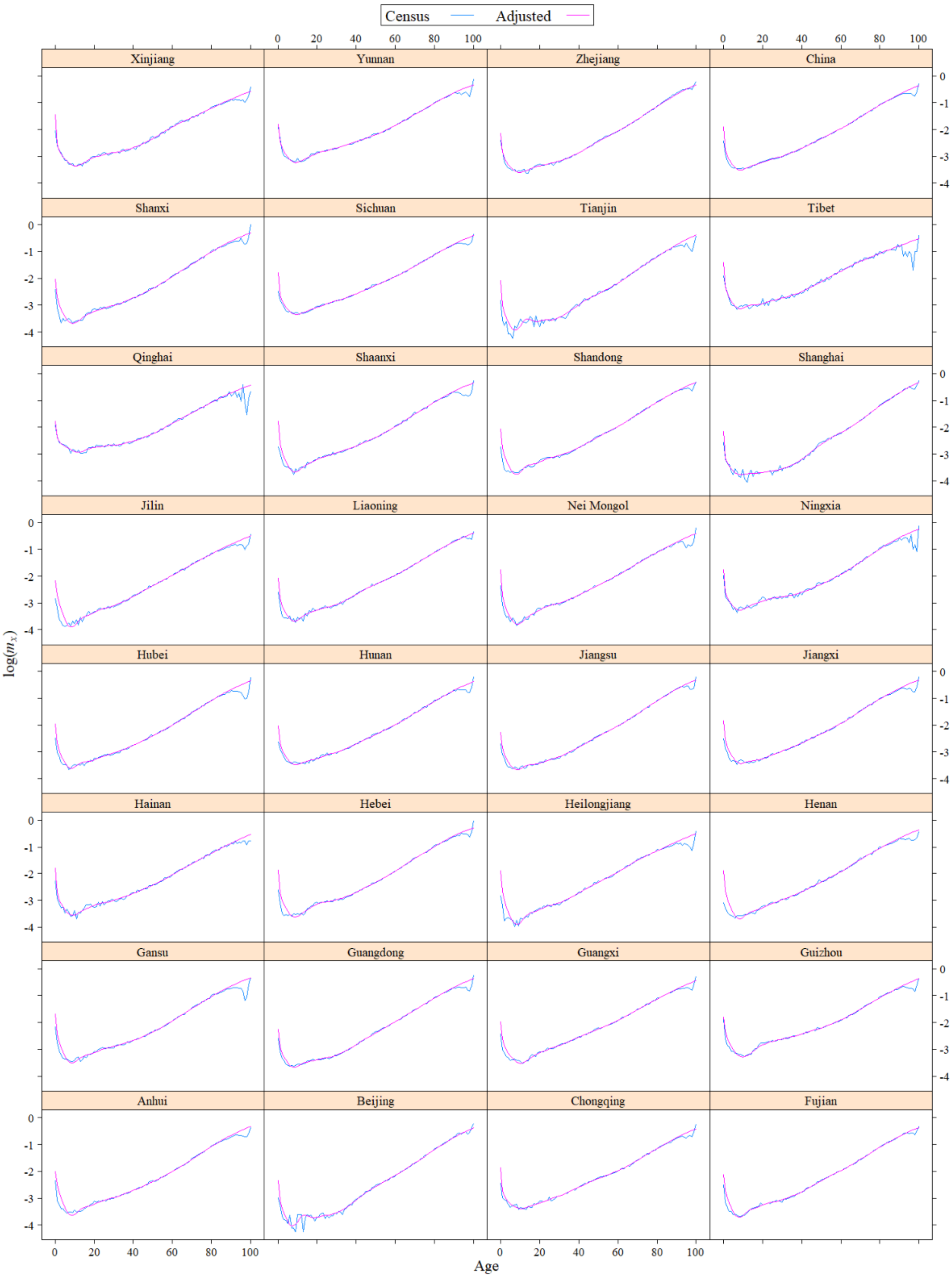

Figure 1a. Provincial male $_1m_x$ in 2010

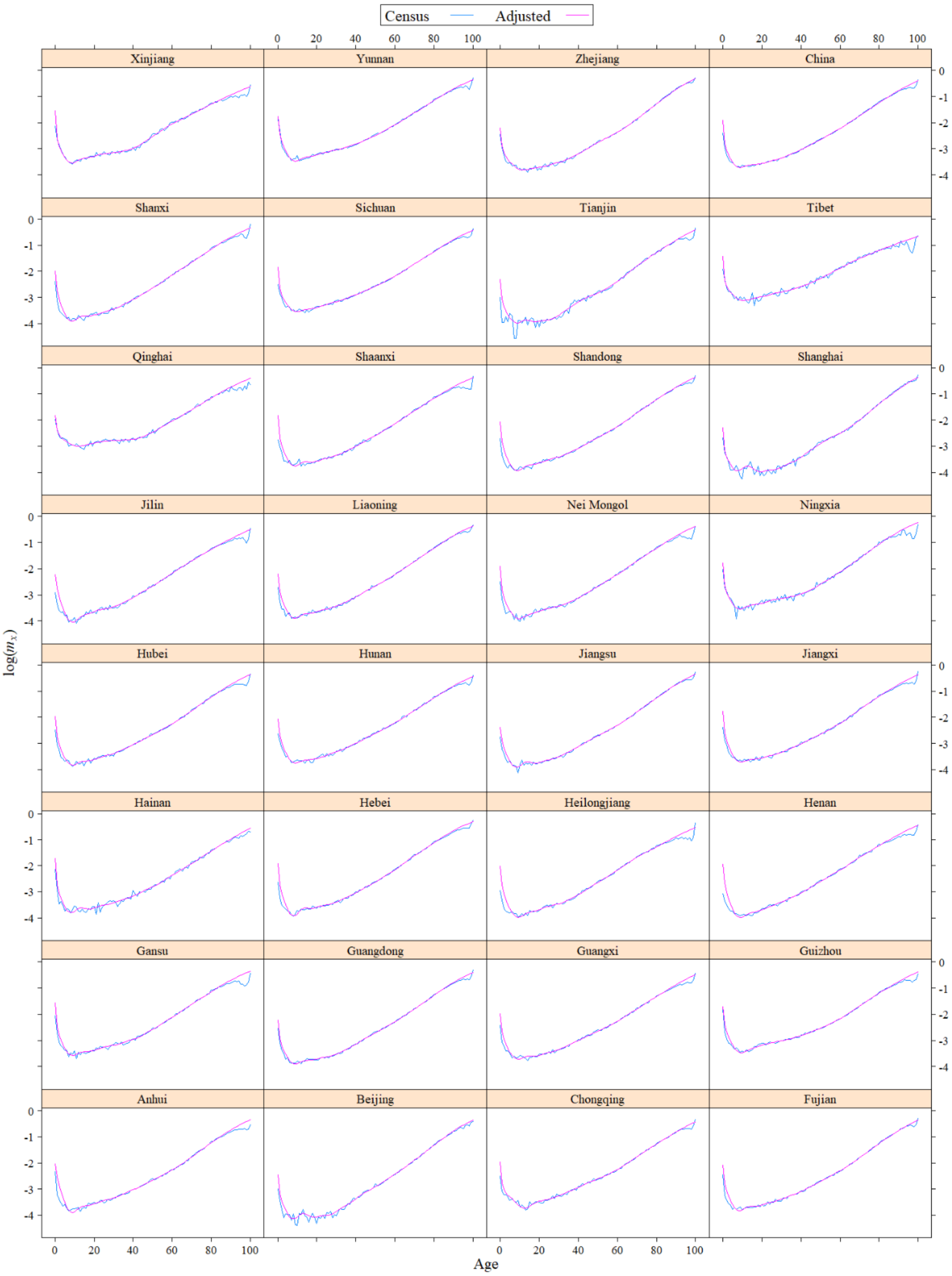

Figure 1b. Provincial female $_1m_x$ in 2010

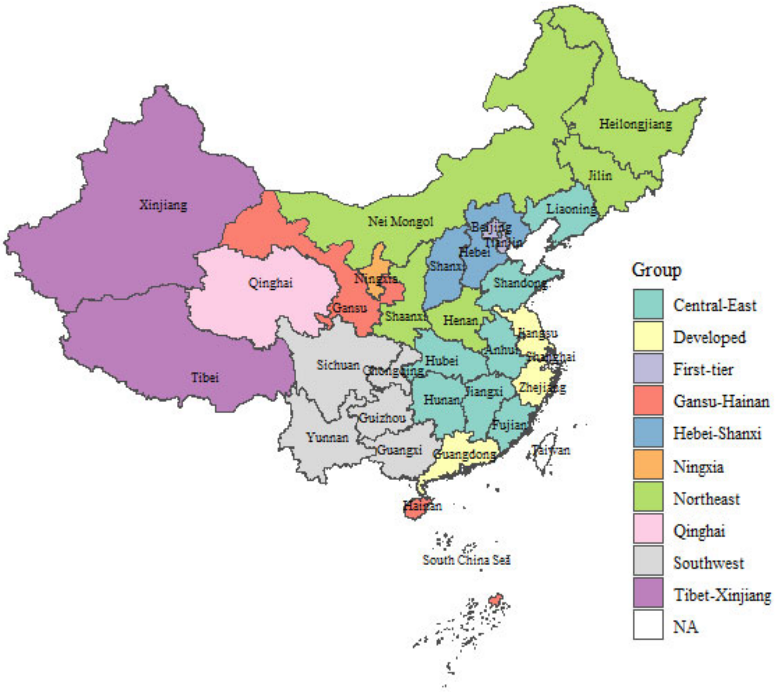

Figure 2. The classification of age patterns of provincial mortality

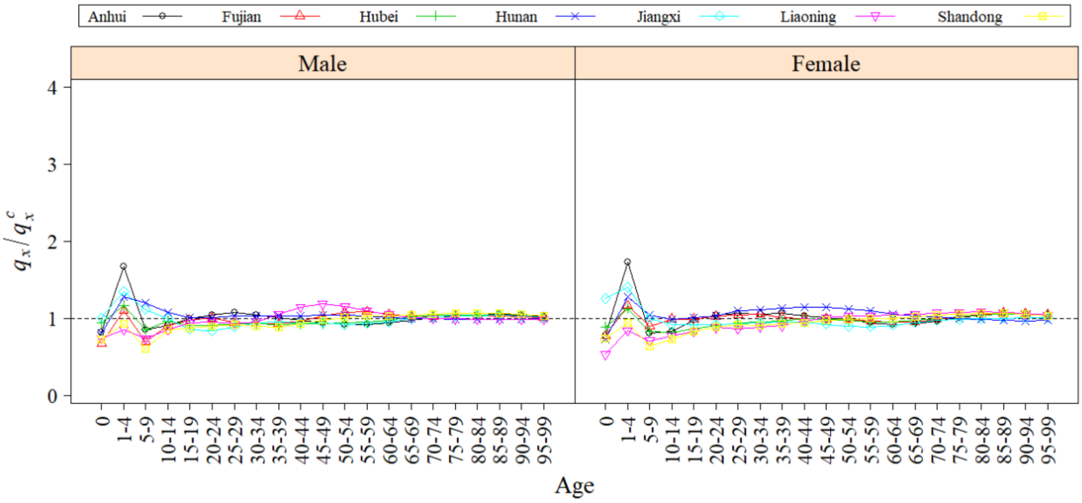

Figure 3a. Central-East group

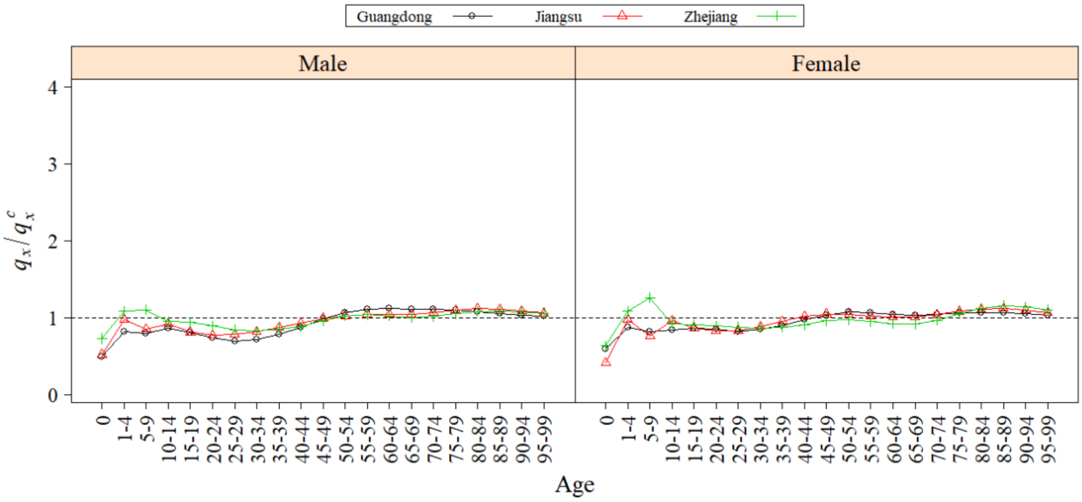

Figure 3b. Developed group

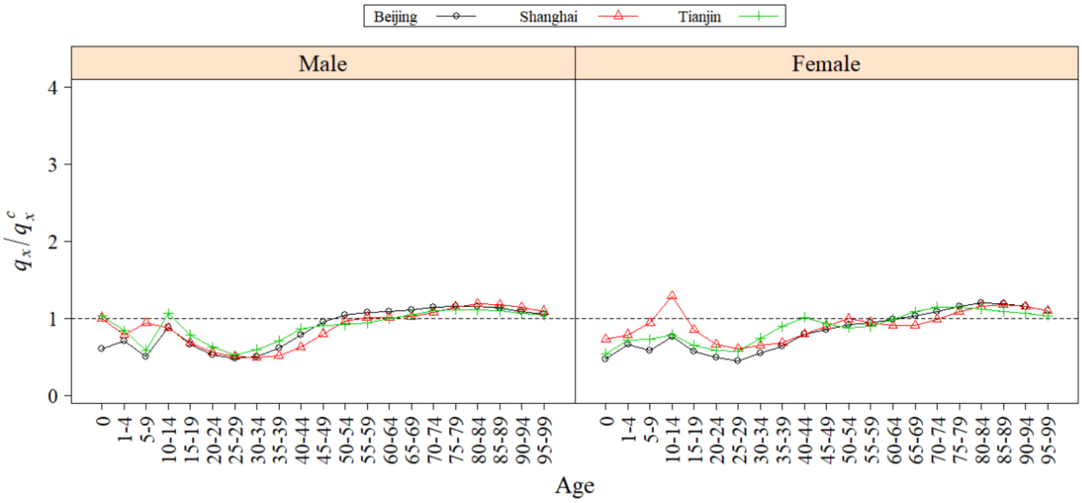

Figure 3c. First-tier group

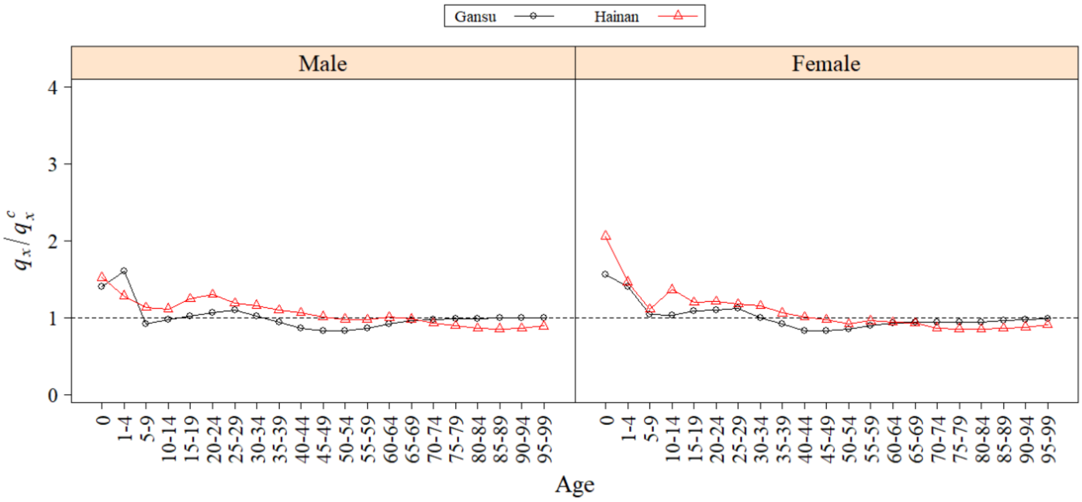

Figure 3d. Gansu-Hainan group

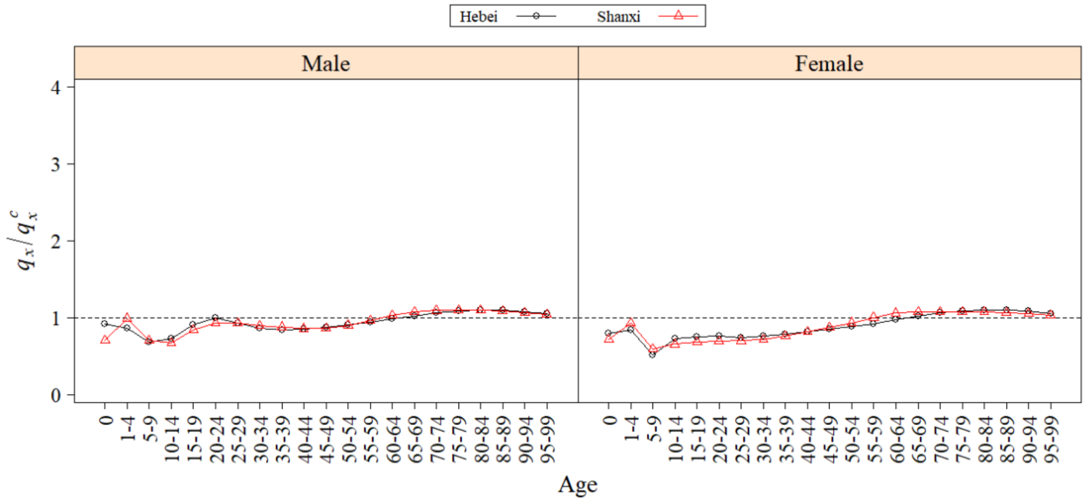

Figure 3e. Hebei-Shanxi group

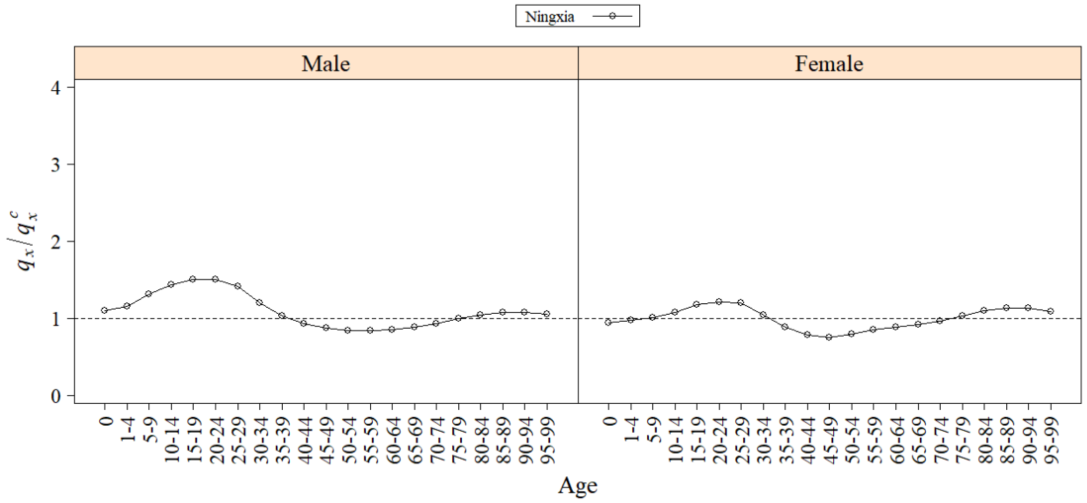

Figure 3f. Ningxia group

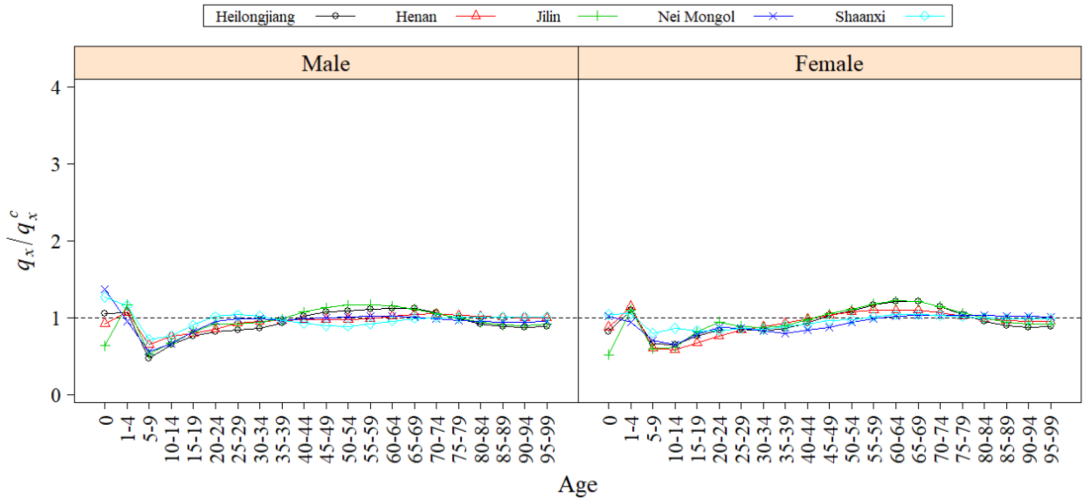

Figure 3g. Northeast group

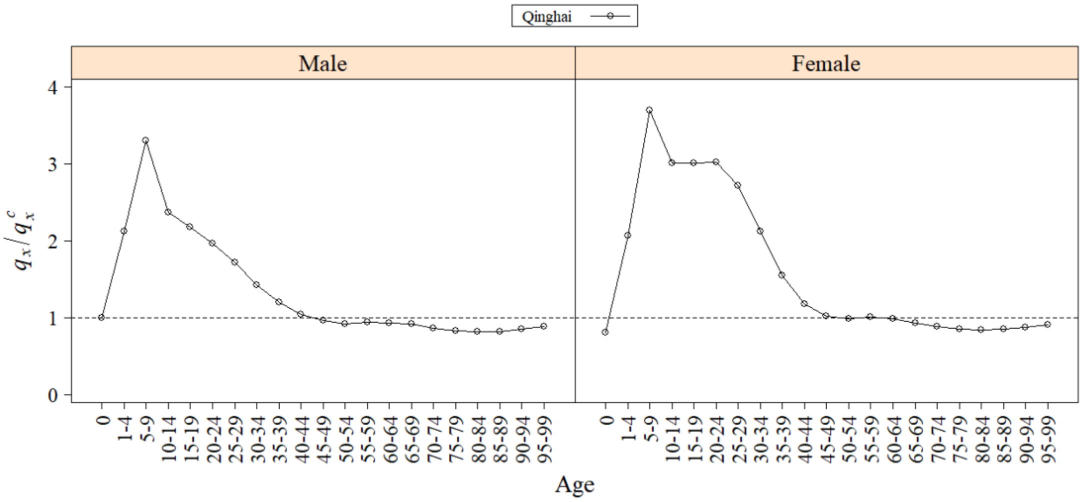

Figure 3h. Qinghai group

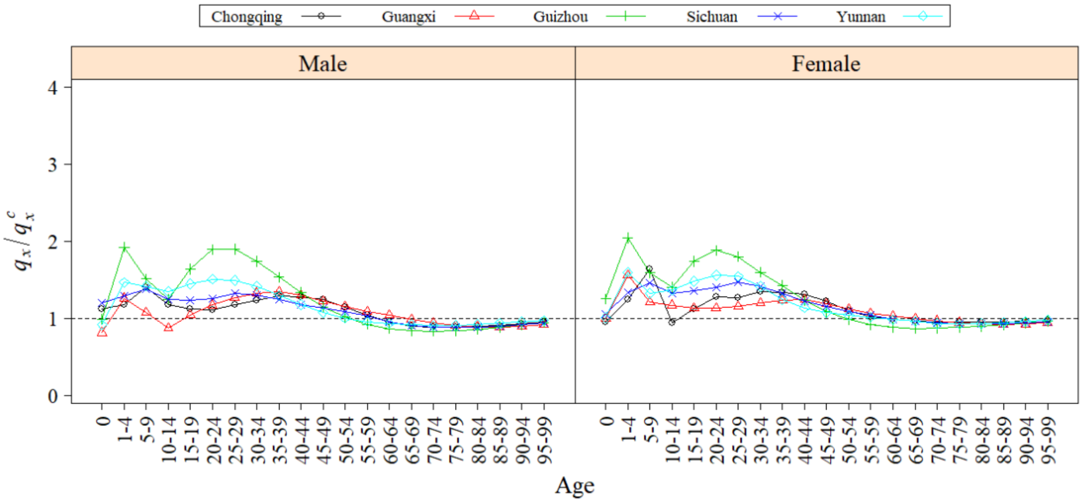

Figure 3i. Southwest group

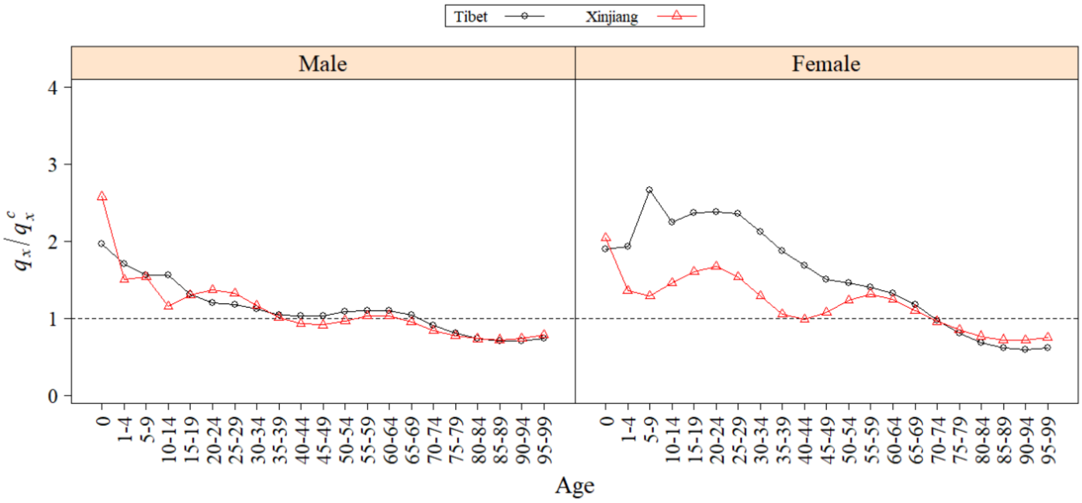

Figure 3j. Tibet-Xinjiang group

Table 1a. Indices of similarity between age patterns of provincial male mortality and model life tables

Province	e_0	Coale-Demeny				United Nations					China Classified				
		W	E	N	S	CH	LA	SA	FE	GE	SW	ME	NC	NE	XJ
Shanghai	80	1.4	1.7	4	1.7	4	3.9	4.1	2.3	2.6	4.1	2.7	1.8	2.3	8.2
Beijing	79.7	1.7	1.9	4.5	2.4	2.8	3.5	3.1	1.7	2.4	4.2	3	1.7	2.2	8.2
Tianjin	79.1	1.8	2.1	3.4	2.1	2.5	2.8	3.1	1.9	1.9	3.1	2.3	1.5	2	7.6
Zhejiang	77.3	2	2.5	2.8	2.6	3	2.5	4.3	2.4	1.7	2	1.8	1.3	1.4	7.5
Hainan	77	3.6	4.2	2.1	4.1	3	1.9	4	4.2	2.8	1.8	3.1	3.5	3.4	4.4
Jiangsu	76.7	1.8	2.2	3.6	2.4	3.9	3.9	5.9	2.3	2.4	2.7	2	1.1	1.6	8.4
Jilin	76.6	2.8	3.1	3.8	3.8	1.8	2.7	3.5	2.8	2.1	2.8	2.4	2.6	2.5	5.4
Guangdong	76.2	2	2.2	3.8	2.9	2.5	3.1	3.5	1.8	1.7	2.6	1.7	1.2	1.4	8.8
Fujian	75.7	2.2	2.8	2.8	2.8	2.1	2.1	4.1	2.4	1.5	2.1	1.9	1.8	1.4	7.1
Liaoning	75.6	2.4	2.9	3	3.5	1.6	2	3.6	2.6	1.7	2.1	2.1	2.3	2	6.8
Hunan	75.5	2.8	3.1	2.3	3.4	1.9	1.4	3.4	2.8	1.6	1.2	2.1	2.4	2.1	6.6
Heilongjiang	75.3	2.6	2.8	3.9	3.8	1.5	2.9	3.2	2.4	1.8	3.1	2.5	2.8	2.8	5.3
Hubei	75.3	1.9	2.4	2.7	2.8	2.6	2.3	4.4	2.1	1.4	1.5	1.7	1.6	1.7	7.3
Shandong	75.2	1.8	2.3	3.2	2.6	3.2	3.6	5.7	1.9	2.1	2.2	1.8	1.3	1.6	7.6
Anhui	75	2.2	2.8	2.4	2.9	3.5	2.9	5.8	2.6	2.2	1.6	2.1	2.1	1.9	7.3
Chongqing	74.9	3.6	4	2.2	4.4	2.6	2	4.1	3.7	2.6	2.1	3.1	3.8	3.1	5.8
Nei Mongol	74.7	2.5	2.8	2.9	3.4	1	2	3	2.4	1.2	1.9	2.2	2.5	2.3	6.1
Shaanxi	74.3	1.9	2.6	2.4	2.8	2.5	2.4	4.9	2.1	1.4	1.5	2	2.1	2	7
Shanxi	74.2	1.3	1.8	3.9	2.6	5.1	5.7	7.7	2.4	3.4	2.6	1.7	1.3	1.5	7.6
Guangxi	74.1	3.4	4	3	4.4	2.6	2.1	4.1	3.7	2.6	2.2	3.4	4.1	3.1	5.5
Henan	73.9	1.9	2.2	3.3	3.1	2.5	3	4.5	1.7	1.6	1.9	1.8	2	1.9	7.5
Sichuan	73.7	3.4	4.1	2.1	4.4	2.7	1.8	4	3.8	2.7	2	3.3	4.2	3.3	5.6
Jiangxi	73.5	2	2.4	2.9	2.7	4.3	4	6.4	2.3	2.5	1.9	1.5	1.9	1.8	7.3
Xinjiang	73.5	4.3	4.7	2.9	4.5	3.6	2.5	4.4	5.1	3.3	2.8	4.3	4.5	4.2	3.5
Hebei	73.2	1.1	1.6	4.6	2.6	7	7.9	9	3.3	4.9	2.8	1.8	1	1.6	7.3
Gansu	72.9	2.2	2.8	2.2	2.8	3.6	2.9	5.6	2.5	1.9	1.2	2	2.3	1.9	7
Ningxia	72	2.3	3.1	3	3.4	8.1	8.1	10.4	5.8	6.6	2.5	3.4	3.1	2.8	6.7
Guizhou	71.4	4.6	5.4	2.1	5.4	3.5	2.5	5.7	4.7	3.7	4	4.7	5.7	5.1	5.7
Yunnan	70.8	3.4	4.2	2.1	4.3	3.4	2.6	6.5	3.5	2.2	2.1	4	4.7	4.1	5.6
Qinghai	70.5	4.8	5.7	2.4	5.8	4.6	2.9	5.6	5.4	4.2	3.3	5.1	6.4	6.1	4.3
Tibet	68.3	3.7	4.3	4.8	5.2	3.1	3.5	4.6	4.4	2.8	3.8	4.7	5.4	4.9	4.7
China	74.8	2.2	3.0	2.2	3.1	1.9	1.7	4.0	2.5	1.3	1.1	1.9	2.2	1.6	6.9

Notes: W: West pattern; E: East pattern; N: North pattern; S: South pattern. LA: Latin American pattern; CH: Chilean pattern; SA: South Asian pattern; FE: Far Eastern pattern; and GE: General pattern. SW: Southwest pattern; ME: Middle and east China pattern; NC: North China pattern; NE: Northeast pattern; XJ: Xinjiang pattern.

Table 1b. Indices of similarity between age patterns of provincial female mortality and model life tables

Province	e_0	Coale-Demeny				United Nations					China Classified				
		W	E	N	S	CH	LA	SA	FE	GE	SW	ME	NC	NE	XJ
Shanghai	84.1	1.9	1.5	3.7	2.1	4.4	4.1	2.9	3.6	3.2	4.2	2.7	2.5	3.2	6.1
Beijing	83.3	2.6	2	4.9	2.9	5.1	5.2	3.3	3.9	4.1	5.4	3.1	2.4	3.5	6.8
Hainan	82.9	2.2	2.5	1.8	2.2	1.7	1	2.6	2.3	1.1	2.1	2.2	3.4	2.6	3.9
Tianjin	82.2	1.8	1.4	4.1	2.8	3.8	3.8	2.7	3.1	3.1	4.2	2.6	1.9	2.8	5.7
Zhejiang	81.6	1.7	1.4	3.5	1.8	5.3	4.4	3.3	4	3.1	3.5	2.4	2.1	3.2	6.8
Guangdong	81.4	1.2	1.3	3.7	2.5	3.2	3.4	2.2	2.5	2.3	3.2	1.9	1.7	2.3	5.6
Jiangsu	81.2	1.5	1.3	3.8	2.4	4.4	4.3	3.1	3.3	2.9	4.2	2.2	1.7	2.7	6.4
Guangxi	81	1.7	2.3	1.7	2.8	1.7	1.2	2.6	1.8	0.8	1.9	1.9	3.1	2.1	3.8
Fujian	80.8	0.9	1.1	3	1.9	3.7	3.2	2.9	2.8	1.9	3.7	1.9	1.8	2.7	5.9
Jilin	80.5	2	2.1	3.6	3.3	2.4	3.1	2.1	1.9	2.1	3.6	1.9	2.1	1.9	4.8
Heilongjiang	80.2	2	2.1	3.4	3.1	2.1	2.9	1.9	1.6	2	3.7	2.1	2.3	2.2	4.4
Chongqing	80.1	1.5	2.1	1.7	2.7	2.1	1.3	2.8	2	1.2	1.8	1.8	3.1	1.9	4.2
Hunan	80	1.3	2	2.5	2.7	2.1	2.1	2.3	1.9	1.1	2.2	1.5	2.5	1.9	4.7
Liaoning	80	1.3	1.3	4	2.5	4.1	4.2	2.6	2.8	2.8	3.9	2.1	1.5	2.6	6.4
Shandong	80	1.1	1.1	3.6	2.2	3.7	4	2.6	2.5	2.5	4.4	2.3	1.6	2.6	5.9
Anhui	79.8	0.9	1.2	3.2	1.8	4.2	3.3	3.1	3.1	2.1	3.5	2	2.2	2.6	5.3
Hubei	79.6	0.9	1.1	3.2	2	3.8	3.6	2.6	2.8	2.1	3.6	2.1	1.9	2.6	5.8
Nei Mongol	79.5	1.3	1.1	3.7	2.1	3.5	3.7	2.1	2.5	2.3	4.4	2.1	1.8	2.5	5.5
Henan	79.3	1.8	2	3.7	3	2.8	3.2	1.8	1.8	2.1	3.7	2	2.1	2.1	4.4
Sichuan	78.8	1.8	2.5	1.2	2.8	2.4	1.5	3	2.2	1.4	1.7	1.9	3.3	2	3.9
Jiangxi	78.6	1.3	1.4	3.2	2	3.7	3	2.3	2.8	1.7	3.2	2	2.1	2.8	5.3
Shanxi	78.4	2	1.6	4.6	2.9	5.7	5.9	2.9	3.8	3.8	4.6	2.9	1.7	3.1	6.8
Shaanxi	78	1.3	1.4	3.3	2.7	3.5	3.7	2.1	2.5	2.1	3.1	2.1	2.1	2.4	5.8
Hebei	77.8	1.9	1.2	4.9	2.7	6.9	7.1	4.1	4.5	4.6	5.1	3.1	1.4	3.6	7.5
Xinjiang	77.6	3.1	3.7	2.8	4	2.4	2.5	3.7	3	2.3	2.8	2.8	3.9	3.5	3.4
Guizhou	76.9	2.6	3.2	0.8	2.8	3.6	2.3	3.2	3	2.1	1.7	2.5	3.9	3.1	3.9
Ningxia	76.2	3.1	1.1	5.8	1.7	8.8	8.6	7.2	7.2	6.8	4.6	3.1	2.4	4	7.2
Yunnan	76.1	1.7	2.5	1.5	2.7	3.6	3	3.1	2.8	1.6	1.8	1.9	3.1	2.5	4.8
Gansu	76	1.4	1.7	3.1	2	4.2	3.6	2.7	3.4	1.9	3.1	1.9	2.3	2.8	5.8
Qinghai	74.4	3.6	4.5	2.1	4.6	4.7	3.2	4.7	4.1	3.1	2.3	3.8	6.5	5.4	4.3
Tibet	71.9	4	4.6	3.5	5.8	3.7	3.3	5.6	4	3.3	3.3	4.6	7.4	5.5	3.6
China	79.6	0.9	1.4	2.7	2.5	2.9	2.8	2.5	2.3	1.5	3.1	1.7	2.0	2.2	5.4

Notes: W: West pattern; E: East pattern; N: North pattern; S: South pattern. LA: Latin American pattern; CH: Chilean pattern; SA: South Asian pattern; FE: Far Eastern pattern; and GE: General pattern. SW: Southwest pattern; ME: Middle and east China pattern; NC: North China pattern; NE: Northeast pattern; XJ: Xinjiang pattern.

Table 2. The provinces in the patterns of China Classified Model Life Table

Pattern	Province
Southwest	Yunnan, Guizhou, Sichuan, Chongqing, Tibet, Shaanxi, Ningxia, Qinghai, Gansu
Middle and East China	Henan, Hubei, Hunan, Shandong, Jiangsu, Anhui, Zhejiang, Fujian, Jiangxi, Shanghai, Guangdong, Guangxi, Hainan
North China	Hebei, Shanxi, Nei Mongol, Beijing, Tianjin
Northeast	Liaoning, Jilin, Heilongjiang
Xinjiang	Xinjiang

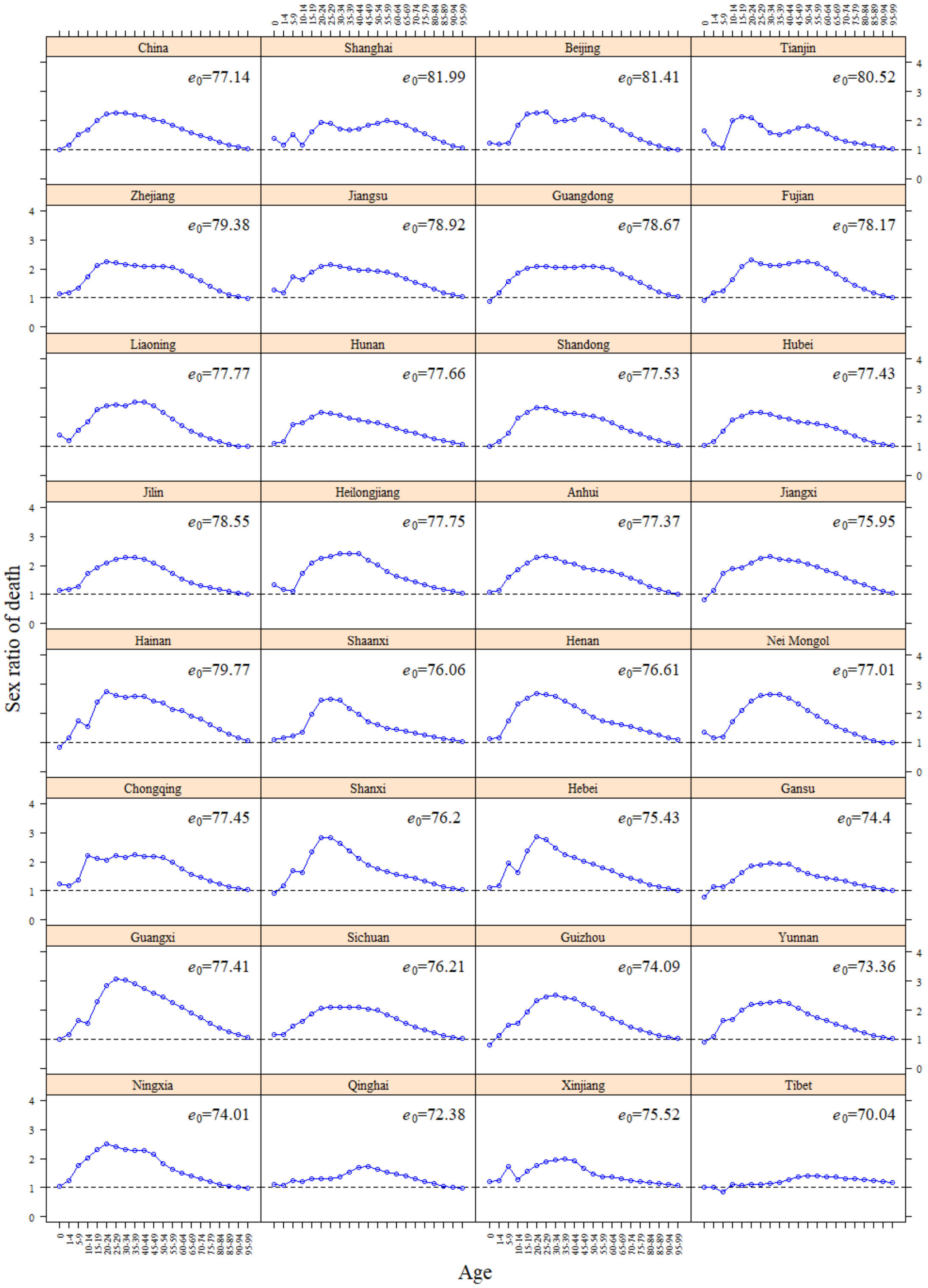

Figure 4 Provincial sex ratio of $_nq_x$ in 2010

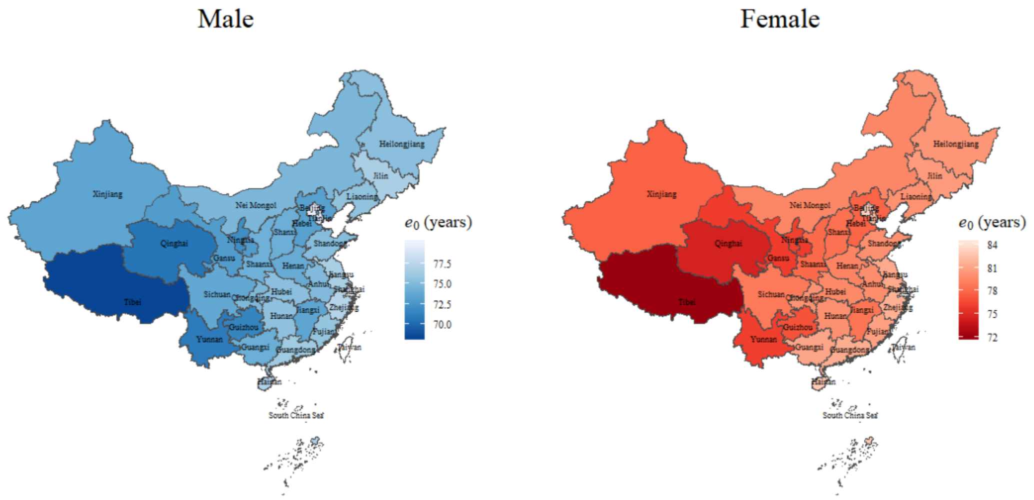

Figure 5a. Provincial life expectancy at birth

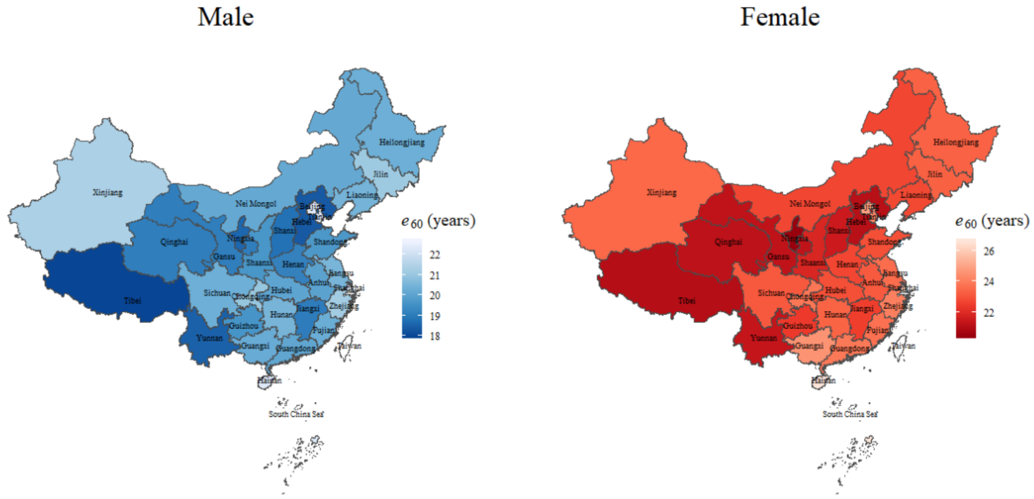

Figure 5b. Provincial life expectancy at age 60

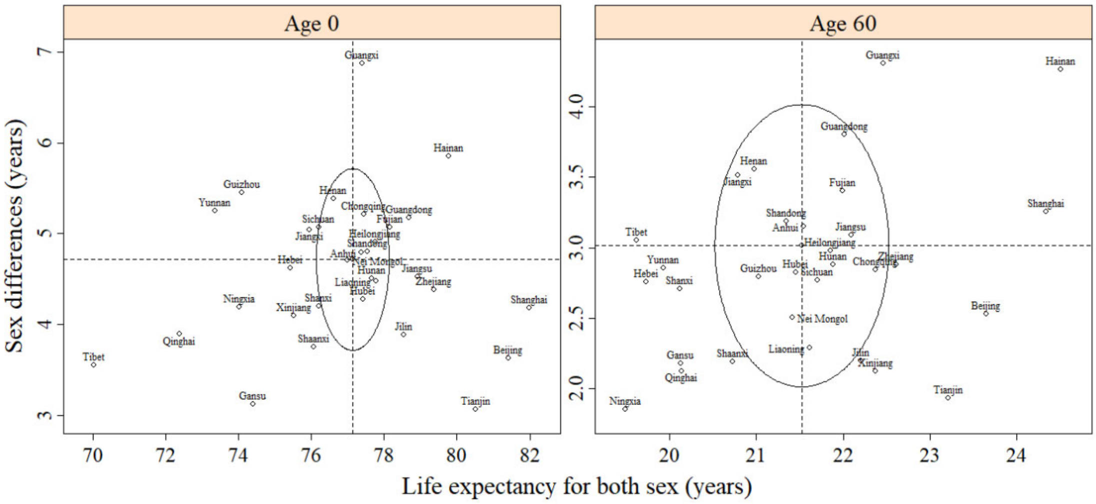

Figure 6. The distributions of life expectancy and their sexual differences by province

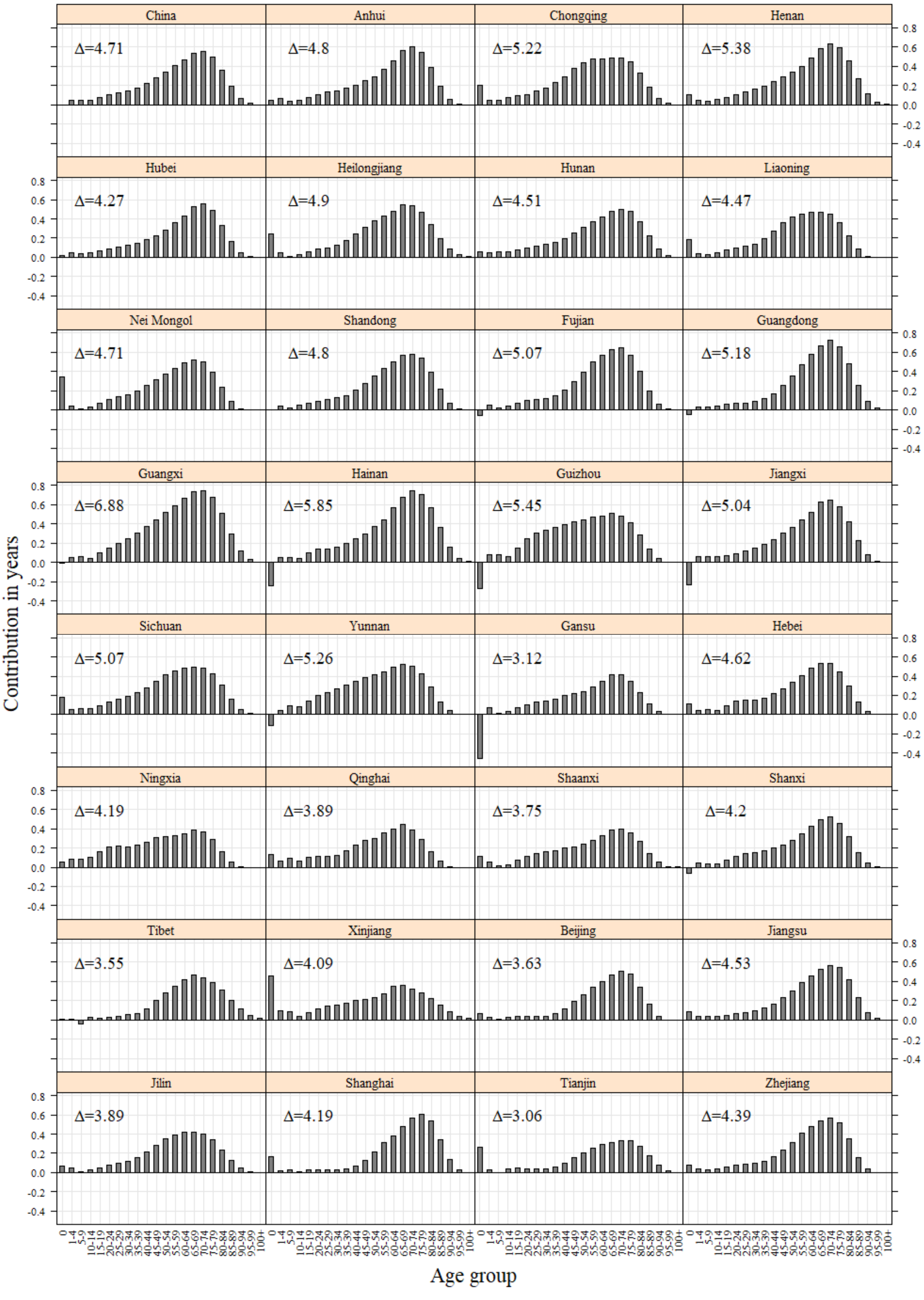

Figure 7. Decomposition of the difference between male and female e_0

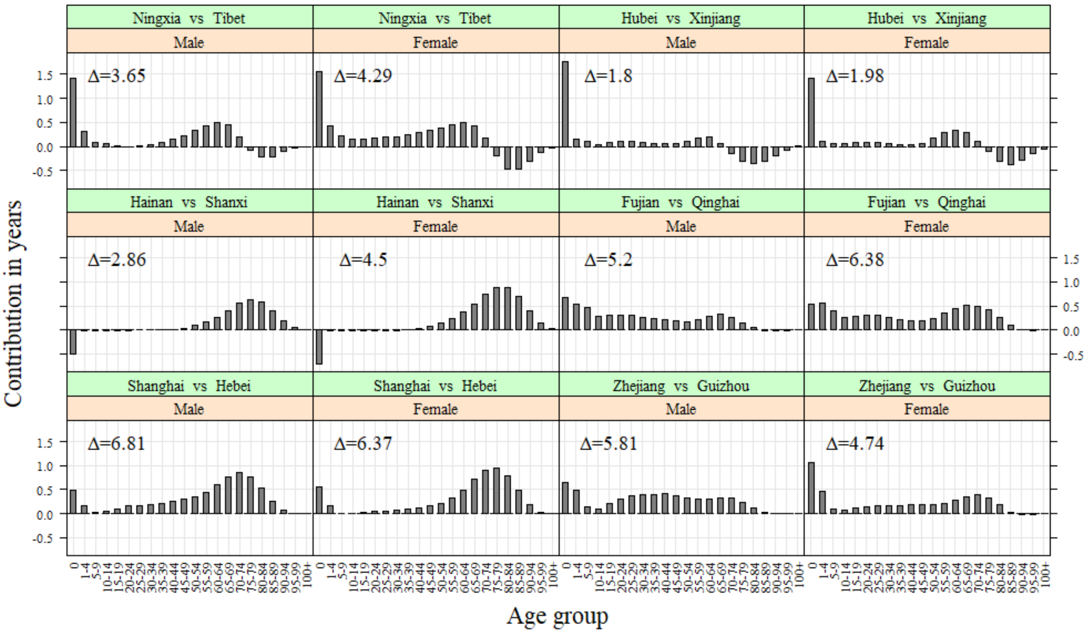

Figure 8. Decomposition of the difference between provincial e_0

Table 3 Provincial life table entropy in China, 2010

Province	Male		Female	
	e_0	H	e_0	H
Anhui	75.01	0.157	79.80	0.131
Beijing	79.65	0.128	83.28	0.107
Chongqing	74.87	0.175	80.09	0.141
Fujian	75.71	0.154	80.78	0.126
Gansu	72.87	0.175	75.99	0.161
Guangdong	76.19	0.146	81.37	0.123
Guangxi	74.14	0.178	81.02	0.141
Guizhou	71.44	0.201	76.89	0.163
Hainan	77.02	0.171	82.87	0.143
Hebei	73.16	0.159	77.78	0.133
Heilongjiang	75.33	0.169	80.24	0.143
Henan	73.95	0.163	79.33	0.140
Hubei	75.35	0.155	79.62	0.132
Hunan	75.47	0.161	79.98	0.138
Jiangsu	76.67	0.142	81.20	0.119
Jiangxi	73.51	0.165	78.55	0.143
Jilin	76.63	0.161	80.52	0.137
Liaoning	75.56	0.159	80.04	0.126
Nei Mongol	74.74	0.169	79.45	0.135
Ningxia	71.97	0.176	76.16	0.143
Qinghai	70.51	0.212	74.40	0.184
Shaanxi	74.25	0.165	78.00	0.144
Shandong	75.16	0.152	79.96	0.129
Shanghai	79.96	0.124	84.15	0.106
Shanxi	74.16	0.154	78.36	0.133
Sichuan	73.72	0.183	78.79	0.150
Tianjin	79.09	0.134	82.15	0.118
Tibet	68.31	0.235	71.87	0.234
Xinjiang	73.55	0.210	77.64	0.184
Yunnan	70.84	0.194	76.09	0.161
Zhejiang	77.25	0.143	81.64	0.116
China	74.84	0.162	79.55	0.140

Appendix I. The adjustment of mortality data and life table compilation

Correcting Mortality under age 5

It seems to be little difficult to correcting provincial mortality under age 5 because China is the country with the preference for son, the discrimination against daughters varies with provincial socio-economic situation, causing higher female 1q0 than male through neglect of girls' health care in many provinces (Attané 2009) and lower sex ratio of 1q0. But the 1q0 in 2010 census is severely underestimated, the sex ratio of 1q0 in census may not embody the reality. Although the ${}_5q_0$ in China subnational MDG 4/5 more accurate, a wide range of ${}_1q_0$ and ${}_4q_1$ combinations can occur at a certain level of ${}_5q_0$ (Guillot, Gerland, Pelletier et al. 2012), and the traditional method based on model life table to estimate ${}_1q_0$ and ${}_4q_0$ at a given ${}_5q_0$ may not be suitable because the pattern of model life table suitable to each province cannot be definitely confirmed beforehand. In this paper we adopted a compromised strategy to correct mortality below age 5: assuming the sex ratio of corrected sex-specific ${}_5q_0$ instead of ${}_1q_0$ is identical with that in census, then correcting provincial sex-specific ${}_4q_1$, and calculating ${}_1q_0$ lastly. In other words, the assumption of this strategy is that the error in ${}_4q_1$ is minor in contrast to ${}_1q_0$, the ground of which is: compared with other age groups, infant mortality underestimate has the maximum possibility to occur for the following reasons: social customs, postnatal death is viewed as an ominous event; technical issue, it's essential to differentiate stillbirth and postnatal death; policy reason, couples and their relatives are not willing to report their "violation" against One-child policy. These factors may exist in other age groups, but its impact is not as significant as that in infant (Huang and Zeng 2013).

Based on the strategy above, firstly sex-specific ${}_5q_0$ can be estimated from non-sex-specific ${}_5q_0$ in China subnational MDG4 by:

$$\begin{aligned} {}_5q_0^M &= {}_5q_0 \big/ \left[w + (1-w)/S \right] \\ {}_5q_0^F &= {}_5q_0^M / S \\ w &= SRB \big/ (1+SRB) \end{aligned} \tag{A.1}$$

where *SRB* refers to the sex ratio at birth and *S* to the sex ratio of ${}_5q_0$ in census. Although birth control departments will fine the families with out-of-plan birth, giving them incentives to hide real birth number, the Ministry of Public Security allow people violating family planning policies to apply for household registration through the opportunities of the 2010 census, which should have encouraged families to report their children's birth and addressed the problem of underenumeration (Cai 2013). And generally, the death underreporting usually exceeds birth underreporting relative to all births (Anthopolos and Becker 2010), therefore, we think, the birth data in census is relative more accurate than death.

The level of ${}_4q_1$ is determined by the illiteracy rate, the capacity of the health facilities in the province and consumption per capita (Banister and Zhang 2005). So, the provincial sex-specific ${}_4q_1$ is corrected by the Loess regression of ${}_4q_1$ against Socio-demographic Index (SDI) in natural logarithmic scale, a summary measure based on income per capita, educational attainment and TFR correlated with health outcomes (GBD 2015 SDG Collaborators 2016). Higher SDI refers to better health outcomes, better well-being, and lower mortality level (Kemon 2017). The ${}_4q_1$ and SDI for regression is the data of 2010 from GBD 2013 Neonatal, Infant, and Under-5 Mortality (Institute for Health Metrics and Evaluation 2014) and GBD 2016 SDI (Global Burden of Disease Collaborative Network 2017). The regression is fitted by the data of 2010 as the relation between mortality and development level may change over time (Preston

1975). The provincial ${}_4q_1$ used for correction and its 95% CI are estimated by provincial SDI, the regression plus Bootstrap method (Efron 1987, DiCiccio and Efron 1996). For a certain province, if the ${}_4q_1$ in census is less than the lower bound, the census ${}_4q_1$ will be replaced by the estimated value, otherwise the census value will be retained. Finally, the corrected ${}_1q_0$ can be calculated by:

$$ {}_1q_0 = \left({}_5q_0 - {}_4q_1 \right) / \left(1 - {}_4q_1 \right) \tag{A.2} $$

The results are listed in Table A1 and A2.

[Table A1 is here]

[Table A2 is here]

Estimating the completeness of death reporting above age 15

Traditionally, the method of estimating the completeness of death reporting above age 15 is Death Distribution Methods (DDM), including Generalized Growth Balance (GGB) (Hill 1987), Synthetic Extinct Generations (SEG) (Bennett and Horiuchi 1981, Bennett and Horiuchi 1984) and the hybrid of the two approaches (GGB-SEG) (Hill, You and Choi 2009). For the research in national perspective, DDMs work well because China’s population fits the assumptions of these methods: it can be treated as a closed population as the international migrants in China can be ignored; the variation in coverage of both deaths and population will have no effect on results for adults; age reporting is of high quality; and census coverage above age 15 did not change significantly (Banister and Hill 2004). However, DDMs are not appropriate to provincial estimate because of provincial population not closed to migration. In 2010, the size of inter-province migration has reached 85.8 million and the highest figure, 21.5 million, happens in Guangdong (Liang, Li and Ma 2014). Bhat (2002) modified GGB to take migration into account and Hill, You et al. (2009) suggest fit GGB and SEG to the age range 30+ to 65+ and take the average of two as the final results to cope with migration. However, due to detail data about age-specific net migration of the intercensal period not public accessible, Bhat’s method cannot be operated; and in our practice the completeness of some provinces calculated by the suggestion of Hill, You et al. (2009) is unreasonable. As a result, this paper adopted Adair and Lopez (2018) empirical formula to estimate the completeness of death reporting:

$$ \begin{aligned} \ln\left(\frac{C^{All}}{1-C^{All}} \right) &= \beta_0 + RegCDRsq * \beta_1 + RegCDR * \beta_2 + \%65 * \beta_3 \\ &\quad + \ln\left({}_5q_0 \right) * \beta_4 + C^{{}_5q_0} * \beta_5 + k * \beta_6 \end{aligned} \tag{A.3} $$

$$ C^{5+} = \frac{RegDeath^{5+}}{\left(\dfrac{RegDeath^{All}}{C^{All}} \right) - \left(\dfrac{RegDeath^{0-4}}{C^{{}_5q_0}} \right)} \tag{A.4} $$

where C^{All} is the completeness of death registration at all ages, $RegCDR$ is the registered CDR, $RegCDRsq$ is the square of $RegCDR$, %65 is the proportion of the population aged 65 years and over, C^{5q0} is the completeness of the registered ${}_5q_0$, k is calendar year, β_0 to β_6 are the coefficients, C^{5+} is completeness at ages five years and over, $RegDeath^{5+}$ is registered deaths at ages 5 years and over, $RegDeath^{All}$ is registered deaths at all ages and $RegDeath^{0-4}$ is registered deaths under age 5.

Extension of abridged life table to complete life table

This procedure is the preparation of re-calculating age-specific mortality at ages 90 and over. The single year mortality in census always suffers from systematic fluctuations brought by age heaping and insufficiently small samples. This paper used United Nations (2017) extending method as reference. For ages from 0 to 4, Heligman and Pollard (1980) formula is utilized to fit ${}_1q_1$, ${}_1q_2$, ${}_1q_3$ and ${}_1q_4$:

$$\frac{q_x}{1-q_x} = A^{(x+B)^C} \tag{A.5}$$

coefficients A, B, C are fitted by Levenberg-Marquardt algorithm (Moré 1978), implemented in R 3.6.1(Team 2019), using R-package *minpack.lm* (Elzhov, Mullen, Spiess et al. 2016). The constraints of probability of death was imposed to ensure that the differences between fitted ${}_1\hat{q}_0$, ${}_4\hat{q}_1$, ${}_5\hat{q}_5$ and the original ones were smaller than the specified tolerance (10E-10). Then ${}_1\hat{m}_0$, ${}_1\hat{m}_1$, ${}_1\hat{m}_2$, ${}_1\hat{m}_3$ were estimated using iteration with Coale, Demeny and Vaughan (1983) formula for age 0 and Greville (1943) formula for age 1 to 4 by the initial values of ${}_1a_0$, ${}_1a_1$, ${}_1a_2$, ${}_1a_3$, ${}_1a_4$ being 0.09, 0.43, 0.45, 0.47 and 0.49 respectively (Chiang 1984).

For ages 5 to 89, ${}_1\hat{q}_x$ was obtained through ${}_1\hat{q}_x = 1 - {}_1\hat{p}_x$, and ${}_1\hat{p}_x$ was interpolated by Piecewise Cubic Hermite Interpolating Polynomial (*pchip*) method: $\sqrt[5]{{}_5p_x}$ was taken as the initial survival probability at ages x+2.5 and the interpolating survival probabilities of for each single year of age using the *pchip* method. A constraint of survival probability during the interpolation was that the difference between the estimated survival probability ${}_5\hat{p}_x$ and the original probability ${}_5p_x$ would be smaller than the specified tolerance (10E-10). An exponential seven-term moving average was performed after the application of the *pchip* method to smooth the estimated ${}_1\hat{q}_x$. The smooth was performed iteratively to ensure the constraint above. After that, we estimated ${}_1\hat{m}_x$ from ${}_1\hat{q}_x$ by assigning an initial value of 0.5 to ${}_1a_x$ for each single year of age.

Re-calculation age-specific death rate at ages 90 and over

The age-specific death rate at advanced ages in 2010 census shows a significant decline compared with other developed countries, about which there is a debate: (Coale and Kisker 1986) held a view that low mortality at advanced ages and over is caused by age overstatement, which is especially obvious in 1982 census (Coale and Li 1991). However, Zeng and Vaupel (2003) considered that such phenomena may be mainly caused by mortality selection in the heterogeneous Chinese population, namely the mortality of strong individuals who survive to this age group is much lower than normal. The discussion for the causes behind this issue goes beyond our research, for convenience and uniform data format, we fitted Kannisto model (Kannisto 1992, Himes, Preston and Condran 1994) to re-calculate age-specific death rate at ages 80 and above, and chosen x=100 as open age group:

$$\mu_x(a,b) = \frac{ae^{bx}}{1+ae^{bx}} \tag{A.6}$$

the parameters a, b are derived by maximum likelihood estimate with approximation of ${}_1m_x \approx \mu_{x+0.5}(a,b)$, the assumption of $D_x \sim Possion(E_x\mu_{x+0.5}(a,b))$ and the log-likelihood function:

$$\ln L(a,b) = \sum_{x=70}^{79} \left[D_x \ln \mu_{x+0.5}(a,b) + E_x \mu_{x+0.5}(a,b) \right] + Constant \qquad (A.7)$$

where D_x stands for deaths and E_x for exposures. The adoption of Kannisto model is on the basis of the conclusions that it has a simpler form and better performance in fitting mortality at ages 80 and over (Thatcher, Kannisto and Vaupel 1998) as well as mortality of China's oldest-old population (Zeng and Vaupel 2003) than other mortality models.

The calculation of life tables

This paper used Coale, Demeny et al. (1983) formula to estimate ${}_1a_0$, ${}_4a_1$ and Greville (1943) formulas to estimate ${}_5a_x$ at ages 5 and over in abridged life table for extension and ${}_1a_x$ for age 1 and over in extended complete life table. The abridged life tables for analysis in this paper are computed directly from extended complete tables, which includes two steps. First, we extract values of l_x, T_x and e_x for x=0,1,5,10, …, 95. Second, we compute ${}_nL_x$, ${}_nd_x$ and ${}_nq_x$ as follows:

$$\begin{aligned} {}_nL_x &= T_x - T_{x+n} \\ {}_nd_x &= l_x - l_{x+n} \\ {}_nq_x &= {}_nd_x / l_x \end{aligned} \qquad (A.8)$$

Appendix II. The confirmation of *α* given e_x by dichotomy iteration

Step 1: confirm the convergence criterion $\varepsilon \leq 10E\text{-}10$;

Step 2: choose artificially $\alpha_{\min}$ and $\alpha_{\max}$ ($\alpha_{\min} < \alpha_{\max}$ and $\alpha_{\min} + \alpha_{\max} \neq 0$), noting that corresponding $e_{0\min}$ should be small, e.g. 5 years, and $e_{0\max}$ are large enough, e.g. 85 years, to ensure the predicted e_0 locates in between $e_{0\min}$ and $e_{0\max}$;

Step 3: substitute $\alpha = 0.5*(\alpha_{\min} + \alpha_{\max})$ into Eq. to calculate corresponding $e_0(\alpha)$;

Step 4: if $|e_0(\alpha) - e^*_0| < \varepsilon$, the iteration ends, otherwise go to Step 5;

Step 5: if $e_0(\alpha) < e^*_0$, $\alpha > \alpha^*$, let $\alpha_{\max} = \alpha$, otherwise $\alpha_{\min} = \alpha$, and then go to Step 3.

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Table A1 Provincial ${}_4q_1$ in 2010 (deaths per 1000)

Province	Male		Female	
	Adjusted	Census	Adjusted	Census
Anhui	6.62 (5.80, 7.42)	2.24	5.75 (5.03, 6.51)	1.53
Beijing	1.70 (1.54, 1.87)	1.11	1.41 (1.28, 1.55)	0.76
Chongqing	4.69 (4.19, 5.20)	3.30	4.03 (3.57, 4.50)	2.49
Fujian	4.08 (3.66, 4.51)	1.78	3.48 (3.12, 3.86)	1.48
Gansu	7.66 (6.70, 8.65)	3.76	6.69 (5.84, 7.65)	3.97
Guangdong	2.88 (2.62, 3.17)	1.91	2.43 (2.21, 2.68)	1.76
Guangxi	5.37 (4.75, 5.98)	2.67	4.62 (4.09, 5.19)	2.24
Guizhou	10.05 (8.78, 11.43)	5.86	8.88 (7.70, 10.25)	4.67
Hainan	4.30 (3.85, 4.76)	3.07	3.68 (3.28, 4.10)	2.28
Hebei	4.10 (3.68, 4.53)	1.66	3.50 (3.13, 3.89)	1.34
Heilongjiang	4.09 (3.67, 4.52)	1.25	3.49 (3.12, 3.87)	1.02
Henan	4.68 (4.18, 5.19)	1.47	4.01 (3.56, 4.48)	1.19
Hubei	4.47 (4.00, 4.96)	2.44	3.83 (3.41, 4.27)	2.03
Hunan	4.87 (4.33, 5.40)	3.29	4.18 (3.71, 4.68)	2.71
Jiangsu	3.27 (2.97, 3.60)	1.98	2.77 (2.50, 3.05)	1.44
Jiangxi	6.13 (5.39, 6.85)	3.23	5.31 (4.67, 5.98)	3.01
Jilin	4.00 (3.60, 4.42)	1.27	3.41 (3.06, 3.78)	1.11
Liaoning	3.22 (2.92, 3.55)	1.63	2.73 (2.46, 3.01)	1.23
Nei Mongol	3.85 (3.47, 4.25)	1.89	3.28 (2.94, 3.63)	1.43
Ningxia	6.03 (5.30, 6.74)	5.07	5.22 (4.60, 5.87)	4.84
Qinghai	6.81 (5.97, 7.64)	11.75	5.92 (5.17, 6.71)	10.80
Shaanxi	4.92 (4.37, 5.46)	2.46	4.22 (3.74, 4.73)	2.09
Shandong	3.64 (3.29, 4.02)	1.31	3.10 (2.79, 3.43)	1.07
Shanghai	1.84 (1.68, 2.02)	1.79	1.53 (1.39, 1.68)	1.38
Shanxi	4.26 (3.82, 4.71)	1.77	3.64 (3.25, 4.06)	1.52
Sichuan	5.66 (4.99, 6.31)	4.18	4.89 (4.32, 5.49)	3.37
Tianjin	2.17 (1.98, 2.39)	0.78	1.82 (1.66, 1.99)	0.52
Tibet	10.35 (9.03, 11.77)	10.69	9.15 (7.94, 10.56)	10.65
Xinjiang	4.21 (3.77, 4.65)	6.57	3.60 (3.21, 4.00)	5.30
Yunnan	7.37 (6.46, 8.31)	8.19	6.43 (5.61, 7.33)	7.55
Zhejiang	3.43 (3.10, 3.78)	3.03	2.91 (2.62, 3.21)	2.37
China	4.02 (3.61, 4.44)	2.77	3.43 (3.07, 3.80)	2.35

Table A2 Provincial $_{1}q_{0}$ in 2010 (deaths per 1000)

Province	Male		Female	
	Adjusted	Census	Adjusted	Census
Anhui	9.89	4.65	9.29	4.74
Beijing	4.45	1.04	3.60	0.99
Chongqing	13.68	3.61	11.05	3.18
Fujian	7.59	3.12	8.30	3.47
Gansu	20.48	6.93	26.50	8.64
Guangdong	5.34	2.53	5.96	2.78
Guangxi	10.57	3.68	10.65	3.85
Guizhou	15.82	13.20	19.46	16.19
Hainan	15.61	5.20	18.65	7.00
Hebei	13.32	2.46	11.85	2.30
Heilongjiang	12.44	1.52	9.35	1.13
Henan	12.32	0.82	11.00	0.84
Hubei	11.01	3.29	10.80	3.38
Hunan	9.32	2.30	8.59	2.33
Jiangsu	5.31	1.98	4.19	1.77
Jiangxi	13.96	3.17	17.00	4.10
Jilin	6.63	1.45	5.75	1.23
Liaoning	8.53	2.56	6.21	1.96
Nei Mongol	16.96	4.27	12.60	3.27
Ningxia	17.39	10.56	16.64	9.49
Qinghai	16.91	11.80	15.12	10.50
Shaanxi	16.42	1.81	14.93	1.75
Shandong	8.66	1.86	8.64	1.96
Shanghai	7.03	2.76	5.05	2.02
Shanxi	9.22	3.81	10.02	4.12
Sichuan	16.20	3.31	13.89	3.06
Tianjin	8.17	1.54	4.92	0.99
Tibet	37.30	11.82	37.23	11.81
Xinjiang	34.39	8.78	28.46	7.36
Yunnan	15.61	12.68	17.07	14.04
Zhejiang	7.07	3.80	6.10	3.49
China	12.28	3.72	12.27	3.91