



The changing trend of life expectancy for the Chinese elderly and its rural–urban disparity

Yuan Peng¹ · Lin Dong¹ · Haili Liang¹ · Liuqing Yang¹ · Sha Jiang² · Shripad Tuljapurkar² · Zhen Guo¹

Received: 6 February 2021 / Accepted: 11 March 2021 / Published online: 29 March 2021
© China Population and Development Research 2021

Abstract

Using data from Population Censuses, 1% National Population Sample Surveys of China and the Human Mortality Database, this article adopts robust percentile-based methods to analyze the changing trend of life expectancy of the Chinese elderly especially the young–old and rural–urban disparity from 1989 to 2015, and attempt to explain the disadvantage of old-age mortality improvement in China compared to developed countries. We find that life expectancy at age 65 in China has increased continuously in recent decades, but at a lower speed than in developed countries, leading to a widening gap between China and developed countries, and the increase in e_{65} has not shown a clear catch-up trend that has been observed in the life expectancy at birth. Similar patterns are found when we explore the rural–urban disparity of China. Based on the age-at-death distribution, we find that the old-age deaths in rural areas are more concentrated at relatively younger ages compared to urban areas due to the higher death risks and slower improvement in mortality of the young–old in rural China. Our findings describe the age-patterns underlying the rural–urban disparity in life expectancy of the elderly within China, and also the main reason for the slower improvement of life expectancy among the Chinese elderly compared with those in developed countries. Survival improvement of the young–old and equalization of available health services are key to reducing the rural–urban bias and achieving accelerated increase in life expectancy among the elderly in China.

Keywords Life expectancy · Robust percentile-based methods · Rural–urban disparity · The young–old

✉ Zhen Guo
guozhen@hust.edu.cn

Extended author information available on the last page of the article

1 Introduction

With the progress of socioeconomic development, the life expectancy of the Chinese elderly is growing. At age 65, life expectancy in China increased significantly from 13.2 years in 1980–1985 to 16.2 years in 2015–2020, slightly higher than the average level of less developed regions (excluding the least developed countries) (16 years), but lower than the world average level (17 years) or the average of more developed countries (19.6 years) (UNPD, 2019).¹ It should be noted that China's economy has been one of the fastest-growing economies in the world during nearly every year since 1978 (Banister et al., 2012), while the gap in life expectancy of the elderly between China and developed countries is widening, from 2.4 years in 1980–1985 to 3.4 years in 2015–2020. Thus old-age survival improvement in China is lagging behind developed countries, and deserves more attention. Research on old-age mortality improvement should provide a basis for achieving the United Nations Sustainable Development Goals 2030 and Healthy China 2030, and is essential for pension planning in China.

The lagging of elderly life expectancy growth is not unique to China. History shows that the life expectancy of the elderly in developed countries has generally tended to increase, but at different rates. While countries such as Japan and France have experienced sustained growth in life expectancy of the elderly, in some periods the United States, Denmark, and the Netherlands have lagged, stagnated or even declined, directly attributable to a slowdown in the rate of mortality decline among those under the age of 80 (Christensen et al., 2010; Crimmins et al., 2011; Jessica & Arun, 2018). Socioeconomic factors such as economic income, education level, social participation, and old-age security also have indirect impacts on the life expectancy of the elderly population (Hoffmann, 2011; Minagawa & Saito, 2015; Norström & Palme, 2010).

Studies on old-age mortality in China mainly focus on trends in life expectancy of the elderly, while insufficient attention has been paid to the speed of life expectancy improvement. Previous studies have shown that the life expectancy of the Chinese elderly population has increased significantly but is still lower than the level of developed countries during the same period (Gu et al., 2013; Wu & Du, 2006). Earlier studies compared the paces of mortality decline of the young–old (ages 65–79) and the old–old (ages 80+) in China and found the decline in mortality among the young–old is the main driver of the life expectancy improvement for the elderly in China, with little decline in mortality among the old–old (Wu & Du, 2006).

¹ The World Population Prospects 2019 revision provides population estimates for the period 1950–2020. Estimates of stocks are presented for every year that is a multiple of five from 1950 to 2020. Estimates of the components of population change are presented for 5-year periods, starting with 1950–1955 and ending with 2015–2020. Stock estimates refer to 1 July of the year in question. All vital rates for any countries and regions are given as the average over the five-year period from mid-year (t) to mid-year ($t+5$) (the next 5-year projection period) centered on 1 January year ($t+3$). For example, the estimate for life expectancy at 65 years for 2015–2020 refers to the period from mid-2015 to mid-2020 (i.e., 2015.5 to 2020.5 in decimal dates), with 1 January 2018 as the mid-point (i.e., 2018.0 using a decimal date) (UNPD, 2019).

However, we do not know from past work whether the paces of mortality decline of the elderly, the young–old and the old–old are faster or slower than other countries. Such comparisons will help identify possible problems of old age survival in China. In addition, most studies in old-age mortality in China use the raw mortality data from population census and population sample census in China, which may bias the conclusions because of poor data quality (Wang, 2013).

Consideration of rural–urban differences is necessary to analyze the mortality improvement in the Chinese elderly. The rural–urban difference of old-age mortality is the embodiment of inequalities in factors such as social and economic status, pension security level, accessibility and availability of health services, etc. (Zimmer et al., 2007). In other words, mortality inequality is the final inequality of the society (Tuljapurkar, 2010). Previous research has established that the life expectancy of the elderly in rural China is not only much lower in absolute terms than that of the urban elderly during the same period, but also its growth rate is not as fast as that of the urban elderly, resulting in a widening rural–urban gap (Wang & Mi, 2013; Wu & Du, 2006; Zimmer et al., 2007). However, previous studies rarely discuss changes and differences in the age distribution of death among the elderly, and there is a lack of attention to the mortality status of the young–old in rural and urban areas.

By employing the robust percentile-based methods measuring the level and age distribution of old-age mortality, this article aims to analyze the changing trend of life expectancy of the Chinese elderly, especially the young–old, and rural–urban disparity, to explain the disadvantage of old-age mortality improvement in China than developed countries. We use our results to put forward corresponding policy recommendations for improving the health and well-being of the elderly and promoting social equity in China. This study contributes to the literature in several ways. First, we calculate the pace of old-age survival improvement in China compared with developed countries to understand whether the pace in China is catching up with the developed world in the face of increasing life expectancy in China. Second, we focus on the age patterns of old-age mortality in China and developed countries, and in rural and urban China. And we particularly highlight the importance of the survival improvement of the young–old. Third, we apply the robust percentile-based methods (Zuo et al., 2018) to simultaneously show central tendency and variability of the age-at-death distribution of the elderly, which could provide a comprehensive picture of mortality in China if reliable data are available. In order to reduce the bias in the conclusions affected by the under-reporting of deaths in the elderly, we use the two-dimensional mortality model (Wilmoth et al., 2012) to estimate the age-specific mortality rates indirectly.

2 Data and measures

2.1 Methods and key indicators

This paper defines the elderly as the population aged 65 years and above, of which 65 to 79 years old are young–old and 80 years and over are old–old. The robust percentile-based methods are used to measure the age-at-death distribution of the

elderly population (Zuo et al., 2018). And we analyze the changes in mortality levels and patterns through indicators such as percentiles, the average of the annual speeds from 1989 to 2015 for age percentiles at 1% intervals, and the age intervals between adjacent percentiles.

For any gender in any year, in the period life table, write $\mu(x)$ for the force of mortality at exact age x and $S(x)$ for the probability that an individual survives from birth to exact age x . Then: $\mu(x) = -\frac{d \ln S(x)}{dx}$, $S(x) = \exp[-\int_0^x \mu(s) ds]$. Given that an individual is still alive at age B ($B \geq 0$), the conditional probability of surviving to the exact age x ($x \geq B$) is: $S_1(x) = \frac{1}{S(B)} \exp[-\int_0^x \mu(s) ds]$. Assume $B = 65$ years old and a specific percentile q , then A_q is defined as the age at which $q\%$ of individuals who are alive at age 65 would die, thus $1 - S_1(A_q) = (q/100)$. Here A_q has two interpretations: (1) for an individual who is alive at age 65, the probability that the individual is dead before age A_q is $(q/100)$ (i.e., $q\%$). And (2) for a population that all individuals alive at age 65, the proportion of the population that would be dead before age A_q is $q\%$. And the age interval between percentiles q_1 and q_2 is: $A_{q_1} - A_{q_2}$.

The robust percentile-based methods combine generality and flexibility. On the one hand, like generalized indicators such as life expectancy and standard deviation of age at death, percentiles can reveal the mortality levels and the disparity of mortality patterns. Firstly, the value of percentile age could illustrate the mortality levels, and the greater the age corresponding to the same percentile q , the lower the mortality rate. Secondly, the age intervals between percentiles demonstrate the disparity of mortality patterns, and since the relative location of A_q depends on the shape of old-age deaths, the larger the age interval between adjacent percentiles, the more discrete the age distribution of old-age deaths, and the more inequality within this age group. On the other hand, percentiles are more flexible, and we could discuss the corresponding A_q and age interval between adjacent percentiles for any given q value depending on the needs. Simultaneously, the percentiles are distinguished from life expectancy in that its calculation involves only the first $q\%$ of the age distribution of deaths and so is unaffected by later deaths (Zuo et al., 2018). This paper mainly uses the ages at 25th, 50th, 75th, and 90th percentiles of death (called A_{25} , A_{50} , A_{75} , A_{90} , and $A_0 = \text{age } 65 \text{ years}$), which could largely reduce the uncertainty of mortality at very-old ages (A_{90} and above).

2.2 Data sources and the mortality estimation in China

Using data from Population Censuses, 1% National Population Sample Surveys of China, the 2019 World Population Prospects and the Human Mortality Database, we analyze the improvement of old-age mortality in China based on international comparison from 1989 to 2015. The underlying data for China were the sex-specific under-five mortality rate (${}_5q_0$) estimated by the United Nations Interagency Group for Child Mortality Estimation (IGME), the under-five mortality rate (${}_5q_0$) published in the “China Health Statistics Yearbook” by rural–urban area, and the sex-specific adult mortality rate (${}_{45}q_{15}$) by rural–urban area from Population Censuses and 1% National Population Sample Surveys of China since 1989.

The two-dimensional mortality model is used to estimate the age-specific mortality rates for all age groups from 1989 to 2015 in China by gender and rural–urban area for 5-year age groups. Since there is a severe death underreporting for child and the elderly in population censuses and 1% National Population Sample Surveys in China since 1990, mortality indirect estimation has become a fundamental work for mortality study (Wang, 2013; Zhang et al., 2017). Compared with other methods, the two-dimensional mortality model has higher flexibility and requires fewer data. And this model has a great performance in terms of flexibility and accuracy in estimating the mortality rate in China (Wilmoth et al., 2012; Zhang et al., 2017). Thus we use the under-five mortality rate and adult mortality rate in China for the corresponding years in the underlying data as two parameters for the two-dimensional mortality,² reconstruct the life tables for China by gender and rural–urban area and get the estimated mortality rate at all ages for 5-year age groups.

From the results (see Table 1), the estimated values of e_{65} for Chinese females are slightly lower than values from WPP2019 and DCMD. The estimated values of e_{65} for Chinese males are between values from DCMD and WPP in 2000 and 2015.³ We consider that the mortality estimation by this model for China is reasonable and the estimated death rate of the elderly could be used as the basis for later analysis. In addition, we find that the death underreporting is greater in rural areas, which is consistent with the previous studies (Li et al., 2018; Zimmer et al., 2007). Thus, the results shown later maybe represent an underestimation of the rural disadvantage in mortality within limits, but is not conflict with the main results of our research.

3 Major findings

3.1 China's diverging trends in life expectancy at age 65

Benefit from the rapid decline in infant and child mortality in the short term, life expectancy at birth in China has increased rapidly from 1989 to 2015, gradually

² It is widely believed that infant and child mortality data from the population censuses and 1% national population sample surveys of China are seriously underreported and cannot be used directly, and there are studies with mixed results on the estimation of under-five mortality rates by urban and rural areas and by gender in China. This paper assumes that there is no significant difference in the sex ratio of infant mortality between urban and rural areas, and finds the sex ratio of child mortality based on the sex-specific under-five mortality rates published by the United Nations, and then distributes the national, urban, and rural under-five mortality rates published in the Health Statistical Yearbook of China according to the aforementioned sex ratios to obtain the rural–urban and sex-specific under-five mortality rates. In addition, we get rural–urban and gender-specific ${}_{45}q_{15}$ of China from the raw data of China's population censuses and population sample surveys, but there still had some risk of mortality underreporting. Therefore, we calculated the underreporting coefficient of ${}_{45}q_{15}$ for the census data of the corresponding year based on the national ${}_{45}q_{15}$ published by WPP2019, and the underreporting level of urban and rural areas was assumed to be the same, finally the ${}_{45}q_{15}$ obtained from the raw data was adjusted by the underreporting coefficient.

³ Regarding most previous studies for mortality estimation by urban and rural areas in China have only published the results for life expectancy at age 0, and there is less discussion on life expectancy at age 65, making it difficult to make comparisons.

Table 1 Life expectancy at age 65 nationwide and by rural–urban areas in China (year)

	Female				Male			
	1989	2000	2010	2015	1989	2000	2010	2015
Nationwide values (WPP2019)	15.0	15.6	16.8	17.8	12.6	13.4	13.9	14.7
Nationwide values (DCMD)	14.9	15.7	16.7	–	12.9	13.8	14.9	–
Nationwide values (estimated)	14.1	14.9	16.6	17.5	13.0	13.5	14.6	15.1
Urban values (estimated)	15.9	17.0	18.6	19.1	13.8	14.8	16.1	16.5
Rural values (estimated)	13.8	14.5	16.0	16.9	12.8	13.2	13.9	14.4

(1) Nationwide values (WPP2019) are from the United Nations World Population Prospects 2019. Since the e_{65} published in WPP2019 is for the 5-year age groups, the average of the two 5-year age groups from 1985 to 1990 and 1990 to 1995 is taken as the approximate e_{65} in 1989, and the subsequent years are treated in the same way. (2) Nationwide values (DCMD) were obtained from the Developing Countries Mortality Database. (3) The nationwide values (estimated), urban values (estimated), and rural values (estimated) were adjusted based on the two-dimensional mortality model in this paper

converging to developed countries (Gui & Chen, 2020). Life expectancy at age 65 (e_{65}) in China has also continued to increase, but still far from developed countries (see Fig. 1). From 1989 to 2015, e_{65} for Chinese men and women increased by 2.1 and 3.4 years respectively, while the average e_{65} of developed countries and regions in HMD (hereafter developed countries) increased by 3.3 and 3.4 years, respectively. The gender difference of the increase in e_{65} is significantly larger in the developed countries (0.1 years on average) than China (-1.3 years), which resulted in a more rapidly widening gap of e_{65} between China and the average in developed countries for males (gap decreased from 1.1 to 2.3 years) than for females.

Comparing the time needed for e_{65} increased from an exact value to another level, which could indicate the improvement of e_{65} at the same mortality transition stage, we found that developed countries with a later start in life expectancy gains have a latecomer advantage, but the catch-up trends of the old-age mortality improvement in China have not been clearly revealed. As shown in Table 2, when e_{65} increased from 13.0 years to approximately 15.1 years for males, it occurred between 1916 and 1987 and took 71 years in Sweden, while the United States experienced a similar growth between 1955 and 1990, and it took 35 years, and Japan even took only 11 years to reach the same gain of e_{65} from 1971 to 1982. We concluded that the later this growth occurred, the less time it took, and this pattern was also observed among women. It is mainly due to the rapid socioeconomic development and technological advances in health care (Cutler et al., 2006). But the situation in China did not quite follow this pattern. It took China 15 and 10 more years than Japan to achieve the same increase in e_{65} for men and women respectively, while the life expectancy improvement in China started much later than in Japan.

Inside China, with the improvements in medical technology and living standards, e_{65} of both urban and rural Chinese has shown a sustained upward trend from 1989 to 2015. However, the absolute value of e_{65} is always lower in rural areas than urban areas. In 2015, e_{65} for rural men and women was 14.4 and 16.9 years, respectively, which was only close to the value for urban elderly around 2000 (see Table 1).

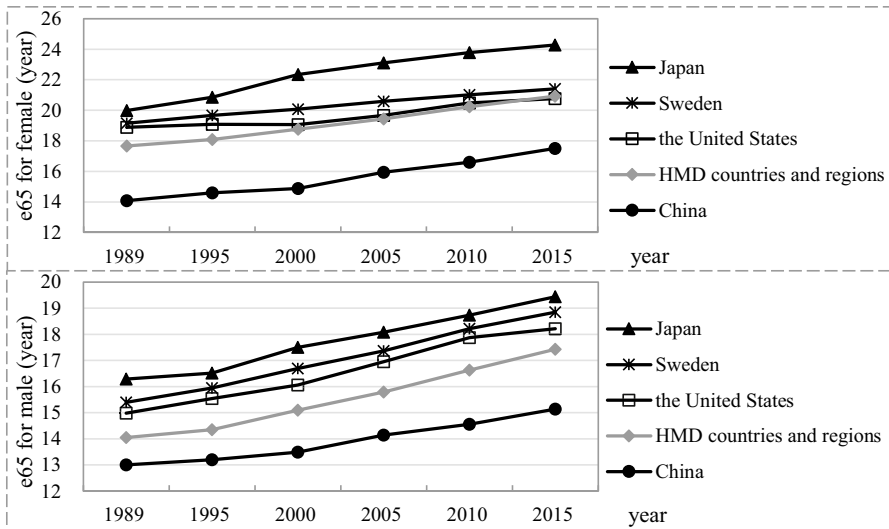


Fig. 1 Life expectancy at age 65, 1989–2015. Source: authors’ calculations using estimated data for China from 1989 to 2015 and data for developed countries from Human Mortality Database. Data of China are estimated by authors based on Population Censuses and 1% National Population Sample Surveys of China

Table 2 Comparison of the length of time spent on equivalent e_{65} increases. Source: same as Fig. 1

	Male			Female		
	Start ($e_{65} \approx 13.0$)	Termination ($e_{65} \approx 15.1$)	Time (year)	Start ($e_{65} \approx 14.1$)	Termination ($e_{65} \approx 17.5$)	Time (year)
Sweden	1916	1987	71	1933	1976	43
The United States	1955	1990	35	1944	1974	30
Japan	1971	1982	11	1962	1978	16
China	1989	2015	26	1989	2015	26

Furthermore, the increase in e_{65} for rural males lagged significantly behind urban males, and the corresponding rural–urban difference has increased from 1.0 years in 1989 to 2.1 years in 2015, showing a significant diverging trend. Among older women, the rural–urban difference in e_{65} also slightly diverged, with a rural–urban gap of 2.1 years in 1989 and 2.2 years in 2015. Overall, compared to urban elderly, the life expectancy of rural elderly population is not only lower but also increases much slowly, thus indicating an obvious disadvantage for old-age population in rural China.

To sum up, even though the life expectancy of the Chinese elderly continues to increase, it is still lower compared with developed countries, and the increasing process has not shown a catch-up trend that has been observed in the life expectancy at birth. In other words, the e_{65} in China did not rise as fast as that of developed

Table 3 Changes in percentiles and percentile age gaps of deaths over age 65 (year). Source: same as Fig. 1

Country	Japan		Sweden		The United States		China	
	1989	2015	1989	2015	1989	2015	1989	2015
Female								
A_{25}	79.7	84.4	78.6	81.2	77.3	79.5	73.7	77.0
A_{50}	85.7	90.4	84.9	87.4	84.4	86.6	79.1	83.1
A_{75}	90.8	95.3	90.1	92.3	90.5	92.4	84.5	88.5
A_{90}	94.9	99.2	94.1	96.5	95.2	96.9	89.1	92.8
$A_{25}-A_0$	14.7	19.4	13.6	16.2	12.3	14.5	8.7	12.0
$A_{50}-A_{25}$	5.9	6.1	6.2	6.2	7.1	7.1	5.5	6.1
$A_{75}-A_{50}$	5.1	4.9	5.2	4.8	6.1	5.7	5.4	5.4
$A_{90}-A_{75}$	4.1	3.8	4.1	4.2	4.7	4.5	4.5	4.3
Male								
A_{25}	75.4	78.6	74.3	78.3	73.4	76.6	72.5	74.4
A_{50}	81.5	85.2	80.5	84.7	79.8	83.7	77.9	80.4
A_{75}	87.0	90.7	86.2	89.8	86.0	89.9	83.4	86.1
A_{90}	91.4	95.0	90.7	93.5	91.0	94.4	87.7	90.6
$A_{25}-A_0$	10.4	13.6	9.3	13.3	8.4	11.6	7.5	9.4
$A_{50}-A_{25}$	6.1	6.7	6.1	6.4	6.4	7.1	5.5	6.0
$A_{75}-A_{50}$	5.5	5.5	5.7	5.1	6.2	6.2	5.4	5.7
$A_{90}-A_{75}$	4.4	4.3	4.6	3.7	5.0	4.5	4.4	4.5

countries, and the gap between them is widening, especially for males. This is mainly due to the low and slow increasing life expectancy of the elderly in rural China.

3.2 Insufficient mortality improvement of the young-old, especially in rural areas

Focusing on the period distribution of old-age deaths, we can see that percentiles increased for all countries and regions. The Chinese elderly have lower percentile ages and slower changing rates than developed countries in the same period, mainly due to the unsatisfied mortality improvement of the elderly in rural area.

Compared with developed countries, the young-old in China has a relatively high death rate with low improving rate, especially for the young-old in rural China. The percentile A_{25} for old-age deaths in China moves steadily away from age 65 but has not reached that value as large as that in developed countries (see Table 3). This means that even the mortality of the young-old is declining in China, it is still higher than the one in developed countries. In terms of domestic differences, the disadvantage of old-age mortality in China relative to developed countries is mainly manifested in the high mortality rate of the rural elderly population. As we can see in Table 4, the A_{25} of the rural older adults is consistently lower than that of urban areas, and the growth rate of A_{25} also lags behind urban areas, particularly for males.

Table 4 Changes in percentiles and percentile age gaps of deaths over age 65 by rural–urban areas in China (year). Source: same as Fig. 1

Gender	Female				Male			
	Rural		Urban		Rural		Urban	
	1989	2015	1989	2015	1989	2015	1989	2015
A_{25}	73.3	76.2	75.3	78.7	72.3	73.5	73.0	75.7
A_{50}	78.8	82.4	81.2	84.9	77.7	79.4	78.7	81.9
A_{75}	84.2	87.9	86.7	90.3	83.1	85.3	84.5	87.4
A_{90}	88.7	92.2	91.1	94.6	87.5	90.0	89.1	91.7
$A_{25}-A_0$	8.3	11.2	10.3	13.7	7.3	8.5	8.0	10.7
$A_{50}-A_{25}$	5.4	6.2	6.0	6.2	5.4	6.0	5.8	6.2
$A_{75}-A_{50}$	5.4	5.5	5.5	5.4	5.4	5.8	5.7	5.5
$A_{90}-A_{75}$	4.5	4.3	4.4	4.3	4.4	4.7	4.6	4.3

From 1989 to 2015, the increase in A_{25} for rural men and women were only 1.2 and 2.9 years respectively, which were lower than those in urban areas (2.7 and 3.4 years respectively). The higher percentiles like A_{50} , A_{75} , and A_{90} in rural areas in 2015 were still lower than the corresponding value in urban areas in 2000.

Further exploring the survival at more advanced ages, we find that the A_{50} of older men in China was 80.4 years in 2015, which was lower than the 85.2, 84.7, and 83.7 years of Japan, Sweden, and the United States in the same year. The A_{50} of Chinese older women moved to 83.1 in 2015, which is even lower than the levels in Japan, Sweden, and the United States in 1989. The result of A_{50} shows that about half of the old-age deaths in China occurred before age 80 in 2015, while some developed countries still had half of old-age people alive at much higher ages (e.g. age 90 for females in Japan). In terms of rural–urban difference, the A_{50} of rural older men in 2015 was 79.4 years old, lower than the 81.9 years old in urban areas. The A_{50} of rural older women moved from 78.8 in 1989 to 82.4 in 2015, which is only close to the level in urban areas in 2000. Therefore, the young–old mortality rate in China is significantly higher than that in developed countries, especially high for rural areas in China.

Looking at the average of the annual speeds from 1989 to 2015 for age percentiles at 1% intervals, we find that the speeds of percentiles gradually increased within the range of A_1-A_{25} for all regions and genders. However, the speeds for percentiles in China, especially in rural areas, tended to lag behind, leading to a gradually widening gap between China and developed countries as well as an enlarging gap between rural and urban China. These two gaps were reaching the maximum around A_{25} (see Fig. 2). This is consistent with the previous finding that the lagging improvement in old-age mortality in China is mainly caused by the slow progress in mortality among the young–old in rural areas.

3.3 Age distribution of old-age deaths

Based on percentile intervals, we find that the old-age deaths in China were more concentrated at younger ages and more dispersed at older ages compared

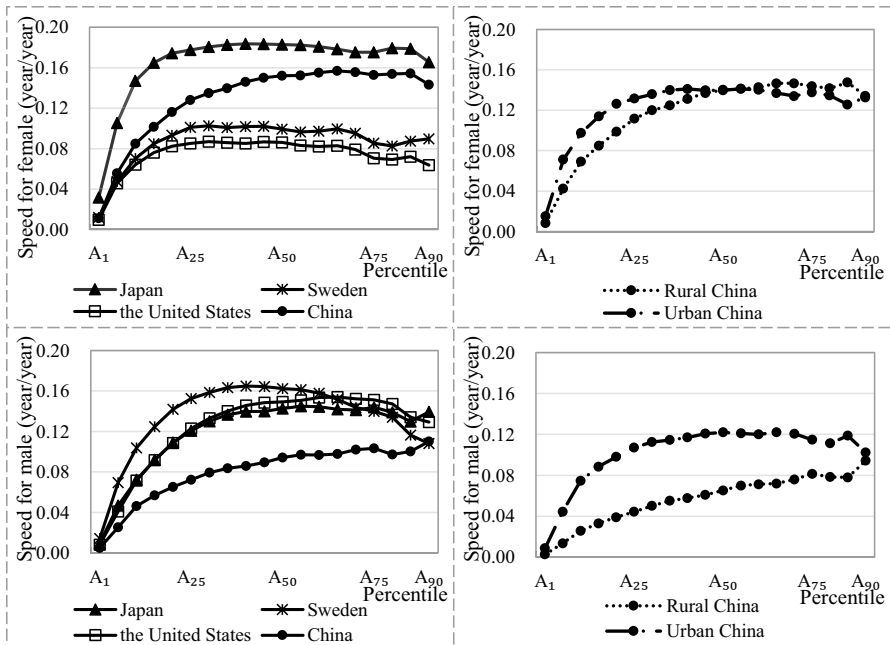


Fig. 2 The average of the annual speeds for age percentiles at 1% intervals from 1989 to 2015. Source: same as Fig. 1

to developed countries. Focusing on younger ages, we find the first two age intervals ($A_{25}-A_0$ and $A_{50}-A_{25}$) showed an increasing trend from 1989 to 2015 in both China and developed countries (see Table 3). This is mainly due to the mortality decline at old ages which results in a gradual shift in the old-age deaths moving towards older ages. However, because of the low and slow increase of percentile ages in China, these two age intervals were generally smaller than those of developed countries, which means the age distribution of the young–old deaths is narrower in China.

At older ages, we find a more dispersed age distribution of deaths. This could be explained by the concentration of old-age deaths in China at younger ages, especially in the rural areas, coupled with the fact that some older adults can survive to very-old ages. In contrast, the mortality of the young–old in developed countries has declined to a lower level, and the age of death is concentrated in higher age groups. Therefore, the age intervals ($A_{75}-A_{50}$ and $A_{90}-A_{75}$) in China are larger than in developed countries in Table 3. Similar patterns were also reflected in the rural–urban disparities in China (see Table 4).

Generally speaking, the elderly population in China, especially in rural areas, tended to die at younger ages. Therefore, the age-at-death distribution of the elderly was narrower at younger ages and the speed of which old-age deaths moved away from age 65 was not as fast as in developed countries. This is the main reason that the rise in e_{65} in China lagged behind developed countries, and also characterizes the major rural–urban disparity in the life expectancy of the elderly in China.

4 Conclusions and discussion

4.1 Conclusions

The study examined the changing trend and rural–urban differentials in old-age mortality in China, and allows several important conclusions to be drawn. First, the elderly in China have a lower life expectancy, a later start in mortality improvement than those in developed countries. But the increase in e_{65} has not shown a clear catch-up trend that has been observed in the life expectancy at birth. Within China, the rural–urban disparity in life expectancy among the elderly has also gradually widened, with the increase in life expectancy for rural elderly lagging significantly behind that for urban elderly, especially among the male population. Second, the slow improvement in mortality among the young–old is the main reason for the slow increase of life expectancy among the Chinese elderly, and the principal cause of rural–urban disparities within China. Third, the old-age deaths in China, especially in rural areas, are more concentrated at younger ages and more dispersed at older ages compared to developed countries. Overall, our results indicate that the elderly in rural China have a higher mortality rate with slow improvement, and they tended to die at relatively younger ages than in urban China, showing that the Chinese rural elderly are still at a significant disadvantage in survival. This rural–urban difference is the main cause that the rise in life expectancy of Chinese elderly population lagged behind that of developed countries and is the final reflection of rural–urban disparity in socioeconomic development, also known as the final inequality.

4.2 Inadequacies in old-age mortality improvement for China

Improved survival of the young–old especially in rural areas is a key factor for health promotion among the elderly and the increase in life expectancy. The major causes of old-age deaths are chronic diseases. These diseases can be effectively prevented or delayed if health problems are detected at younger ages and early health interventions and treatment services are used. Therefore, a focus on improving the health status of the young–old is critical for the survival improvement of the elderly. At the individual level, the healthy young–old are likely to experience better health when they live to older ages than those in poor condition. At the aggregate level, when fewer deaths occur in the young–old, it is natural to envision a situation where there are more old–old in the future. In addition, for a given rate of mortality decline, the gain in life expectancy is larger by reducing mortality at younger age. As mortality decrease in the young–old accelerates, the gap in life expectancy between China and developed countries can be narrowed. However, to some extent, scholars and policy-makers have neglected the importance of survival improvement of the young–old in China. We argue that fundamental and applied research focuses more on the survival of the old–old than of the young–old, as do public health policies and practices. The death risks of the young–old deserve more attention.

The significant rural–urban difference of old-age mortality in China also deserves attention. From the perspective of the medical insurance system, China's former

rural cooperative medical system collapsed after the Reform and Opening-up, and the rural public medical mechanism was absent for a period of time (Zhao et al., 2020). Rural residents had obstacles in seeking medical services and faced higher health risks than urban residents. After the reconstruction of the universal medical insurance system, the medical insurance level for rural residents is still lower than that of urban areas, which has limited the reduction in the risk of death among the elderly (Liu & Guo, 2020). In terms of the distribution of health resources, although medical and health services in both urban and rural areas of China have improved significantly, the rural–urban gap in aspects of financial, material and human resources is still widening. Medical and health expenditures are tilted toward the urban areas, resulting in an excessive health resource concentration. As a result, the medical and health infrastructure and technical staffing in rural are falling behind the urban (He, 2011; Zheng, 2019). To sum up, rural residents have lower medical insurance levels and less access to healthcare services than urban residents. The health care needs of the rural elderly are not being met effectively, which is not conducive to increasing the life expectancy of the rural elderly.

4.3 Efforts and implications to improve health status for the Chinese elderly

In order to improve the health status of the rural elderly and reduce the mortality disparity between urban and rural areas, the Chinese government has made many efforts. In recent years, China has launched a series of policies such as the Health China Action plan, elevated elderly health as a critical content to the national strategy level, and implemented specific actions for elderly health promotion and chronic disease prevention and treatment. In addition, rural–urban health inequality has always been a concern. The Chinese government has been helping poor people to access medical resources and health services through actions like health poverty alleviation, promoting a unified health insurance system for urban and rural residents, and providing policy guarantees for preventing and treating chronic diseases in the rural elderly. However, the enormous challenges facing China cannot be ignored either. According to the World Population Prospects 2019, the proportion of the population aged 65 and over in China is expected to increase by 14.1 percentage points in the next 30 years, from 12.0% in 2020 to 26.1% in 2050, exceeding developed countries such as the United States (22.4%) and Denmark (24.2%) in 2050. The growth in the proportion of the elderly in China over the next 30 years is 2.2 times as much as the increase in the past 30 years (1990–2020), indicating that China would enter a stage of accelerated aging.

Considering the population challenges that China will face in the near future, we propose the following strategies to address old-age mortality. First, the government needs to strengthen the social welfare system and improve senior-care capabilities to ensure the basic livelihood security of the elderly. Taking advantage of the traditional culture of filial piety, the government can also help to create age-friendly environments to achieve a higher level of health and well-being for all of the elderly. Second, given the health inequality between urban and rural areas, effort should be exerted to break down urban and rural biases of economic development, medical

services, health insurance, and social policies. Moreover, health inequality exists in the elderly with differing socioeconomic status. The government needs to incline the policy towards the vulnerable elderly to promote health equalization.

4.4 Limitations

This paper has the following limitations. First, the estimation methods of mortality data for the elderly need to be further improved, especially mortality estimation by rural or urban areas. Second, we have not studied in depth the effects of macro-institutional environment and individual socioeconomic status on the lagging improvement in mortality of the elderly in rural areas, especially for males and the young-old.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

References

- Banister, J., Bloom, D. E., & Rosenberg, L. (2012). Population aging and economic growth in China. In M. Aoki & J. Wu (Eds.), *The Chinese economy: A new transition* (pp. 114–149). Palgrave Macmillan.
- Christensen, K., Davidsen, M., Juel, K., Mortensen, L. H., Rau, R., & Vaupel, J. W. (2010). The divergent life-expectancy trends in Denmark and Sweden—And some potential explanations. In E. M. Crimmins, S. H. Preston, & B. Cohen (Eds.), *International differences in mortality at older ages: Dimensions and sources*. The National Academies Press.
- Crimmins, E. M., Preston, S. H., & Cohen, B. (Eds.). (2011). *Explaining divergent levels of longevity in high-income countries*. The National Academies Press.
- Cutler, D., Deaton, A., & Lleras-Muney, A. (2006). The determinants of mortality. *Journal of Economic Perspectives*, 20(3), 97–120.
- Gu, D., Gerland, P., Andreev, K., Li, N., Spoorenberg, T., & Heilig, G. (2013). Old age mortality in Eastern and South-Eastern Asia. *Demographic Research*, 29(38), 999–1038.
- Gui, S., & Chen, J. (2020). Average life expectancy of the Chinese population in 1949–2019: Trends, contributors and prospects. *China Population and Development Studies*, 3(2), 142–153.
- He, L. (2011). The urban-rural gap of medical and health public services and the path of equalization. *Finance & Economics*, 12, 114–120. **(in Chinese)**.
- Hoffmann, R. (2011). Socioeconomic inequalities in old-age mortality: A comparison of Denmark and the USA. *Social Science & Medicine*, 72(12), 1986–1992.
- Jessica, Y. H., & Arun, S. H. (2018). Recent trends in life expectancy across high income countries: Retrospective observational study. *BMJ*, 362, k2562.
- Li, J., Liu, R., & Zhang, L. (2018). Exploring methods of making urban and rural life tables in China. *Chinese Journal of Population Science*, 3, 62–72, 127. **(in Chinese)**.
- Liu, Y., & Guo, A. (2020). Impact of medical insurance system on the mortality risk of the elderly: A survival status analysis based on CLHLS data. *Chinese Journal of Health Policy*, 13(4), 17–23. **(in Chinese)**.
- Minagawa, Y., & Saito, Y. (2015). Active social participation and mortality risk among older people in Japan: Results from a nationally representative sample. *Research on Aging*, 37(5), 481–499.
- Norström, T., & Palme, J. (2010). Public pension institutions and old-age mortality in a comparative perspective. *International Journal of Social Welfare*, 19(s1), S121–S130.

- Tuljapurkar, S. (2010). The final inequality: Variance in age at death. In B. S. John (Ed.), *Demography and the economy*. University of Chicago Press.
- UNPD. (2019). *World population prospects: The 2019 revision*. United Nations Population Division.
- Wang, J. (2013). Trends in life expectancies and mortality patterns in china since 1990: A further examination and analysis. *Population Research*, 37(4), 3–18. (in Chinese).
- Wang, X., & Mi, H. (2013). Mortality improvement analysis for Chinese population. *Statistical Research*, 30(2), 58–63. (in Chinese).
- Wilmoth, J., Zureick, S., Canudas-Romo, V., Inoue, M., & Sawyer, C. (2012). A flexible two-dimensional mortality model for use in indirect estimation. *Population Studies*, 66(1), 1–28.
- Wu, C., & Du, P. (2006). *Population aging in China: Changes and challenges*. China Population Press. (in Chinese).
- Zhang, Z., Dai, Z., & Yang, J. (2017). Evaluating the two-dimensional mortality model for mortality study in China. *Chinese Journal of Population Science*, 1, 81–91, 127–128. (in Chinese).
- Zhao, Z., Jia, H., & Chen, M. (2020). Major socioeconomic driving forces of improving population health in China: 1978–2018. *Population and Development Review*, 46(4), 643–676.
- Zheng, J. (2019). Study on the equilibrium of health resource allocation in China. *Chinese Health Resources*, 22(5), 362–366. (in Chinese).
- Zimmer, Z., Kaneda, T., & Spess, L. (2007). An examination of urban versus rural mortality in China using community and individual data. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 62(5), S349–S357.
- Zuo, W., Jiang, S., Guo, Z., Feldman, M. W., & Tuljapurkar, S. (2018). Advancing front of old-age human survival. *Proceedings of the National Academy of Sciences*, 115(44), 11209–11214.



Yuan Peng is a Ph.D. student in the School of Sociology, Huazhong University of Science and Technology. Her research interests include mortality, longevity and population health.

Lin Dong is a Ph.D. student in the School of Sociology, Huazhong University of Science and Technology. Her research interests include fertility, gender imbalance and inequality in mortality.

Haili Liang is a Ph.D. student in the School of Sociology, Huazhong University of Science and Technology. Her research interests include sex imbalance and mortality, education and population projection.

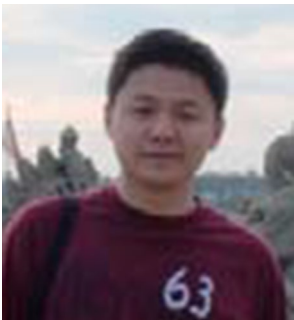
Liuqing Yang is a master student in the School of sociology, Huazhong University of Science and Technology. Her research interests include education, fertility and mortality.



Sha Jiang is a Ph.D. student in the Department of Biology at Stanford University. Her research interests include old-age mortality, fertility and sex imbalance.



Shripad Tuljapurkar is Professor of Biology and the Dean & Virginia Morrison Professor of Population Studies at Stanford University. His research areas include stochastic dynamics of human and natural populations; life history evolution, especially senescence; prehistoric societies; and probability forecasts including sex ratios, mortality, aging and fiscal balance.



Zhen Guo is Professor and the Assistant Dean of the School of Sociology, Huazhong University of Science and Technology. He received his Ph.D. from Xi'an Jiaotong University in 2013. He was a Visiting Ph.D. student at Department of Sociology at the University of Victoria in 2011, and a Visiting Associate Professor at the Morrison Institute for Population and Resource Studies at Stanford University in 2015. His research focuses on population development strategy, gender imbalance and fertility in China, as well as the population health and mortality.

Authors and Affiliations

Yuan Peng¹ · Lin Dong¹ · Haili Liang¹ · Liuqing Yang¹ · Sha Jiang² ·
Shripad Tuljapurkar² · Zhen Guo¹ 

Yuan Peng
pengyuan617@hust.edu.cn

Lin Dong
donglin@hust.edu.cn

Haili Liang
lianghelly@163.com

Liuqing Yang
liuqing_yang@hust.edu.cn

Sha Jiang
jiangsha@stanford.edu

Shripad Tuljapurkar
tulja@stanford.edu

- ¹ School of Sociology, Huazhong University of Science and Technology, Wuhan 430074, People's Republic of China
- ² Department of Biology, Stanford University, Stanford, CA 94305, USA