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Urban–rural lifespan disparities and cause-deleted analysis: evidence from China

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ABSTRACT

Objectives To examine the length and dispersion level of lifespan for the subnational populations in China, identify the urban–rural gap and sex differences, and analyse the contribution made by causes of death.

Setting Cause-specific mortality data extracted from the Chinese Disease Surveillance Points system, grouped by sex and urban/rural residence.

Primary outcome measures Life expectancy and lifespan disparity are used to measure the length and dispersion level of lifespan, respectively. Cause-specific contributions are obtained by contrasting cause-deleted life expectancy and lifespan disparities with observed values.

Participants Aggregated national data gathered from over 605 surveillance points across China, covering over 264 million people by 2016 (about 19.14% of the total Chinese population).

Results In the decade under observation, all subpopulations in China, by area and sex, experienced increases in life expectancy and decreases in lifespan disparity, while causes of deaths contributed differently. For example, based on the 2016 data, if cardiovascular diseases were deleted, there would be an increase in life expectancy that ranges from 5.59 years for urban males to 6.69 years for rural females. However, also lifespan disparity would increase, ranging from 0.81 years for urban females to 1.37 years for rural males.

Conclusions In China, the urban–rural gaps in both life expectancy and lifespan disparity are shrinking as the rural residents are catching up fast, while the gender gaps remain large, and even widening. Causes of death with different age distribution patterns contribute differently to the level and direction of the urban–rural and sex differentials in life expectancy and lifespan disparity. Sex differentials were observed in cardiovascular diseases, respiratory diseases, lung and liver cancers, and external causes, while urban–rural differences were found in lung and breast cancers, and external causes.

INTRODUCTION

The past 40 years have witnessed perhaps the most drastic changes in Chinese society. Since the Reform and Opening in 1978 and the enactment of the one-child policy 1 year after, China experienced rapid economic growth and significant changes in population structure.[1] While the rapid economic development has led to a general improvement in China's population health and a reduction in mortality,[2 3] there are rising concerns about whether the health inequality has been growing, especially given the increasingly uneven distribution of wealth, knowledge and medical resources in the country.[4 5] An emerging body of literature on the health gaps in China has shown that rural areas lag behind urban areas in the epidemiological transition, and that females have longer life expectancy (e_0) than males.[6 7]

Most of these studies have attempted to estimate the level of health inequality in China by simply comparing life expectancies, child and maternal mortality rates or other health indicators across population groups.[8–11] However, little research has been conducted to measure health inequality or dispersion within a group.[12] Some studies have adopted lifespan disparity ($e^†$)[13] as an indicator to effectively estimate the level of dispersion in the length of life within a population.[14–17] Analyses based on historical data from developed countries suggest a strong negative relationship between life expectancy and lifespan disparity,[15–17] yet this trend has

been challenged recently with findings from more countries and discussions on how health inequality is affected by contextual factors.[14] The lack of such evidence from China makes it difficult to quantitatively understand the health inequality situation in the country and hinders further discussion on this matter.

This study makes an effort to fill this gap by measuring the urban–rural, male–female life expectancy and lifespan disparity in China with the latest available data, examining the impacts made by different causes of death to these longevity measures, and looking into how the impacts vary across areas and sexes. Our research question focuses on the existence of the negative relationship between e_0 and $e^\dagger$ in Chinese subpopulations, and to what extent causes of death contribute to their changes.

METHODS
Patients and public involvement
Patients or the public were not involved in the design, conduct, reporting or dissemination of this study.

Data sources
Data used in this study are derived from the Chinese Disease Surveillance Points (DSP) data[18 19] produced by the Chinese Center for Disease Control and Prevention (CCDCP). The definition of urban and rural areas in this paper is in accordance with the legal designation implemented in the country.

The main data source used in this paper is the DSP for the years 2006 and 2016. The data comes from over 605 surveillance points across the country, covering over 264 million people by 2016 (about 19.14% of the total population). The DSP data are representative of the regional population, as a multistage cluster probability sampling strategy with stratification at three levels is adopted. This dataset contains information on age-specific death rates, causes of death, and the structure of the population covered (all aggregated at the regional level). Such information allows researchers to produce regional life tables and conduct further analysis. There is under-reporting in the DSP data, especially among the population groups aged 0–5 and over 85. To minimise the impact of under-reporting and ensure the reliability of analytical results, we adjust the child mortality rates for under-reporting by using data from Maternal and Child Health Surveillance system[20] as a reference. Age-specific death rates were smoothed using the two-dimensional log-quadratic mortality model[21] and the 'Ungroup' package built in R V.4.0.3,[22] and the old-age mortality was extrapolated until age 110 and more using the Kannisto model[23] (see online supplemental appendix 1 for mortality data before and after adjustment).

The DSP data also provide information on the causes of death. In this paper, we study the impacts on life expectancy and lifespan disparity brought by the leading causes of death, including cardiovascular

diseases (CVD), cancers (as well as specific cancers of lung, liver, stomach, colorectal, breast and prostate), respiratory diseases, external causes, diabetes, digestive diseases and neuropsychiatric disorders (online supplemental table S1 includes details of diseases matching between the CCDCP, the Global Burden of Diseases[24] and the International Classification of Diseases revision 10).

The measure of lifespan inequality
This paper chooses lifespan disparity $(e^\dagger)$[13] to measure dispersion in lifespan, or the average number of years lost due to death. Using the life table notation of $d(x)$ to denote the death distribution, $e(x)$ the remaining life expectancy at age x and ω as the last age interval then lifespan disparity is calculated as $e^\dagger = \int_0^\omega d(x)\,e(x)\,dx$.

Lifespan disparity measures the difference of individual lifespan, or disparity in age at death within a population. The notion is that if high inequality in lifespan exists in a population, some people would die significantly earlier than others, and their early deaths would contribute to more loss of life years compared with deaths at older ages, so the larger value of $e^\dagger$ indicates higher inequality, while zero means perfect equality. As such, $e^\dagger$ can be interpreted as the years of life lost in the population, which is easy to understand and communicate, as opposed to other measures of dispersion such as Standard Deviation or the Gini index.

Disease-specific contribution
The impact of a particular disease on life expectancy and lifespan disparity is examined by deleting the deaths due to this specific cause. With information from the life tables and cause-specific death counts, cause-deleted life tables were produced,[25 26] and the cause-deleted life expectancy and lifespan disparity were derived from there (online supplemental appendix 3 includes details on this technique). The results section presents the changes produced in the two measures when causes of death are deleted. Differences between the age components of the lifespan disparity of the cause-deleted and original life tables were used to assess the age-specific contribution of a cause to the lifespan disparity and presented in online supplemental appendix 4.

RESULTS
Figure 1 shows the lines of changes in life expectancy and lifespan disparity of each subpopulation between 2006 and 2016 (online supplemental appendix 5 also presents the level of lifespan disparity for other selected populations in the world in comparison with subpopulations in China). Though males have shorter life expectancies and higher lifespan disparities than the female populations, all the population groups have experienced improvements in life expectancy
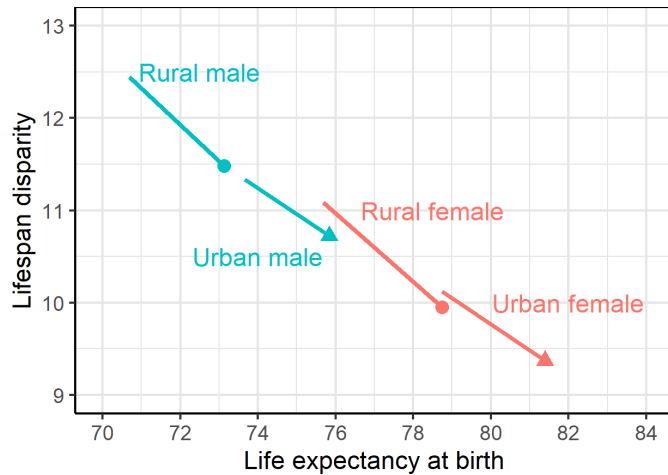
Figure 1 Chinese life expectancy and lifespan disparity, by sex and location, 2006–2016. The line indicates the change between 2006 and 2016, with the end with dot/triangle being the data of 2016. Data source: authors' calculations derived from data from the Chines Disease Surveillance Points (DSP) 2016.

Figure 2 Cause-deleted life expectancy and lifespan disparity, by sex and location, and for the four leading causes. Data source: authors' calculations derived from data from the Chines Disease Surveillance Points 2016. CVD, cardiovascular disease.

and lifespan disparity over the decade. In the urban area, life expectancy has increased by 2.17 years (from 73.66 to 75.83) for males and 2.65 years (from 78.74 to 81.39) for females, meanwhile the lifespan disparity has decreased by 0.61 years (from 11.33 to 10.72) for males and 0.75 years (from 10.12 to 9.37) for females. As indicated by the length of lines, rural residents have experienced faster improvements than their urban counterparts during the 10 years of observation, with life expectancy increasing by 2.44 years (from 70.69 to 73.13) for rural males and 3.06 years (from 75.68 to 78.74) for rural females, and lifespan disparity decreasing by 0.97 years (from 12.45 to 11.48) for rural males and 1.14 years (from 11.09 to 9.95) for rural females. Compared with the urbanites, rural dwellers have experienced more reductions of lifespan disparity for the same unit of improvement in life expectancy across the decade, which is indicated by the different slope of the lines (downward incline from left to right). Over the same years, the gap between male and female life expectancy has expanded from 5.08 years to 5.56 years in the urban area and from 4.99 years to 5.62 years in the rural area. The sex gap in lifespan disparity widened from 1.21 years to 1.35 years among the urban residents and from 1.36 years to 1.53 years among the rural dwellers.

Both life expectancy and lifespan disparity are subject to the influence of deaths from various causes. Our analysis suggests that in 2016, CVD, cancers, external causes and respiratory diseases are the four leading causes of death in both urban and rural China (see online supplemental appendix 6). Figure 2 presents the cause-deleted life expectancy and cause-deleted lifespan disparity for each of the four causes in comparison with the observed life expectancy and lifespan disparity in 2016.
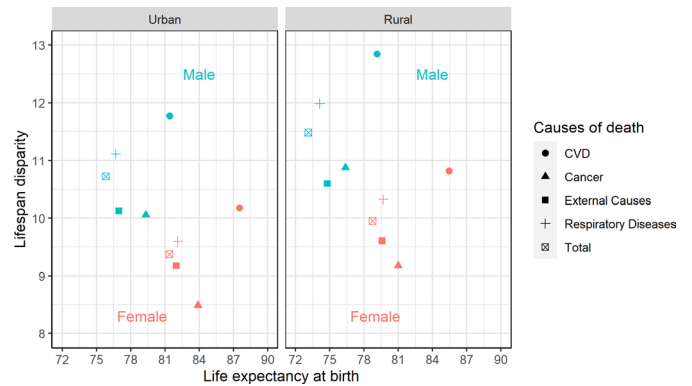
Several observations could be made based on the information from figure 2. Though the deletion of deaths from each cause would bring improvements in life expectancy, the elimination of deaths from some diseases, such as CVD and respiratory diseases, could actually drive up the lifespan disparity. The degree of improvement in life expectancy varies. In general, all populations would benefit most from the deletion of CVD-induced death, followed by deaths from cancer, external causes and respiratory diseases. The greatest improvement in life expectancy could be made by deleting deaths caused by CVD, especially for rural females. By doing this, the rural female life expectancy could increase by as much as 6.69 years (from 78.75 to 85.44), but their lifespan disparity would also increase by 0.86 years (from 9.95 to 10.81).

Cancer ranks as the second top cause of death in China, and it is a larger contributor to overall mortality in urban areas as compared with rural ones, especially for males. In the urban area, the impacts on life expectancy and lifespan disparity brought by cancer are ranking next to the effects of CVD. Thus, deleting deaths from cancers would widen the urban–rural difference in life expectancy by 0.20 years (2.70 vs 2.90) for males, and by 0.27 years (2.64 vs 2.91) for females, meanwhile slightly changing the rural–urban gap in lifespan disparity for males (0.76 vs 0.80) and females (0.57 vs 0.68).

Compared with deaths from CVD and cancer, deaths due to external causes and diseases in the respiratory system carry less influence on lifespan disparity and life expectancy but show more sex differences. Both respiratory diseases and external causes have more potent influences on life expectancy and lifespan disparity of males than females. The urban and rural male life expectancies would increase by 1.14 years (from 75.83 to 76.97) and 1.65 years (from 73.13 to 74.78), respectively, after deleting deaths due to external causes, while the lifespan disparities would decrease by 0.59 years (from 10.72 to 10.13) and 0.88 years (from 11.48 to 10.60), respectively (details of the mechanism acting on the cause-deleted analysis are presented in online supplemental appendix
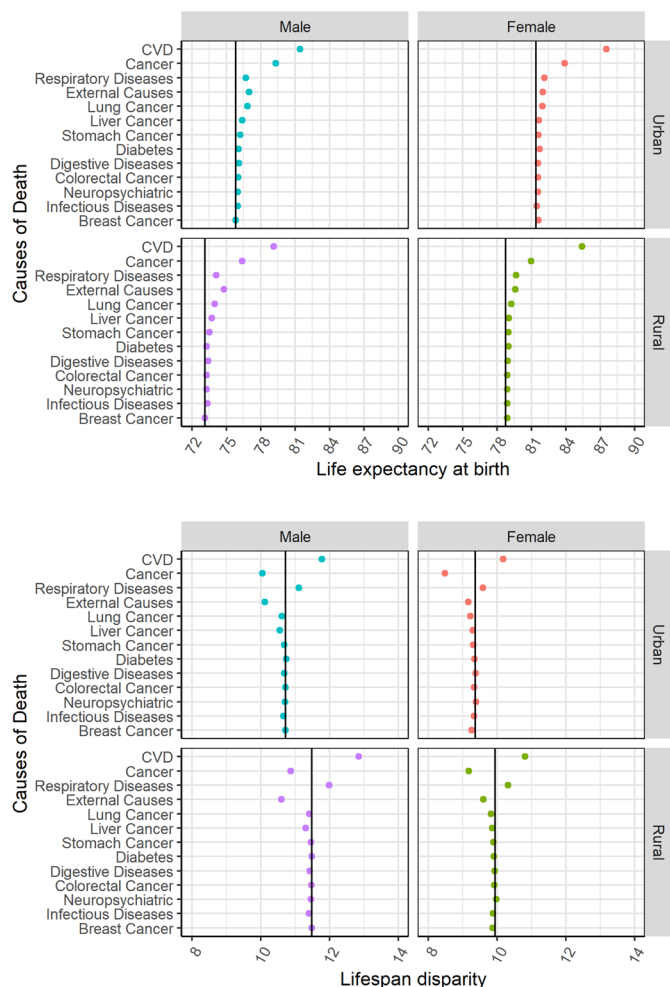
Figure 3 Cause-deleted life expectancy and lifespan disparity, by sex and location, and for 13 selected causes. The vertical line in each panel represents the value of the original life expectancy/lifespan disparity in the population data source: authors' calculations derived from data from the Chines Disease Surveillance Points 2016. CVD, cardiovascular disease.

7). By deleting deaths caused by respiratory diseases, the urban male and female life expectancy would increase by 0.87 years (75.83–76.70) and 0.74 years (81.39–82.13), respectively. At the same time, the lifespan disparity would increase by 0.39 years (10.72–11.11) and 0.23 years (9.37–9.60).

The differences between cause-deleted and observed life expectancy and lifespan disparities for 13 different causes are presented in figure 3. Although deleting all these causes would increase life expectancy, only the elimination of deaths due to CVD, respiratory diseases, diabetes (for males), neuropsychiatric disease (for females) would increase lifespan disparities, and deleting deaths from all other causes would reduce the lifespan disparity to various degrees. This observation suggests that the contribution to lifespan disparity made by a specific cause of death is closely related to the distribution of this type of death across age. To further understand the role of the age distribution of deaths, the age components

of difference in lifespan disparity (observed vs cause-deleted) are plotted in online supplemental appendix 4.

DISCUSSION

With the unfolding of epidemiological transition across the globe, evidence[27–29] suggests that deaths are shifting from younger to older ages, and when the reduction in young-age mortality surpassed the decline in old-age mortality, decreases in lifespan disparity would accompany the increases in life expectancy as a consequence. However, much of the literature used data from developed countries in Europe and North America. It has not been clear if China and its subpopulations, with unique features in many aspects, would follow the same path. Our findings demonstrate that between 2006 and 2016, subpopulations in China have all experienced an increase in life expectancy and decrease of lifespan disparity simultaneously, which is consistent with what has been found in countries such as the United States, Sweden, France, Italy and Japan.[15 17] This result supplements the previously available evidence of life expectancy improvement in China at the national level[30–32] and fills the research gap in the lifespan disparity of subnational Chinese populations. Through our analysis, it has been noticed that despite the universal improvement, urban–rural and male–female differences still exist. Urban populations have a higher life expectancy and a lower level of inequality in the length of life than their rural counterparts, and females generally outperform males. Existing literature has emphasised the urban–rural health difference in China,[33 34] but our findings show that the urban–rural gaps in life expectancy and lifespan disparity are narrowing due to the fast catching up of the rural population while the gender gap keeps expanding (similar to the experience of Japan).[35 36] Even rural females are in a more advantageous position than urban males. The shrinking of the urban–rural health gap in China is potentially connected with the lifted living standards in the rural area after several rounds of poverty reduction campaigns, and the improved coverage of medical insurance in the rural area since the establishment of the New Rural Cooperative Medical Scheme in 2003.[37 38]

To further understand the dynamics between life expectancy and lifespan disparity, we analysed the role of causes of death by using the cause-deleted method. Similar to what has been found in previous literature,[39] we find that though life expectancy would certainly increase after deleting deaths from a cause, at the same time, eliminating deaths due to some causes could drive up the lifespan disparity while others lead to a reduction. After further looking at the age component of cause-deleted lifespan disparity, we confirm this difference could be corelated with the age distribution of deaths (see online supplemental appendix 4). If a considerable number of deaths from a cause occur at younger ages, such as external causes, the deletion of this cause could result in a reduction in lifespan disparity, and the opposite is true for a

cause of death featuring more deaths in old ages, such as CVD and respiratory diseases. This is closely related to the threshold age which divides deaths of young and old ages and their effect of decreasing and increasing the lifespan disparity, respectively.[40] Our results for China subpopulations from 2006 to 2016 indicate that the causes of death opposing the decline in lifespan inequality were offset by the greater number of causes that were aiding the decline. It should be noted that though we use the cause-deleted method for analysis, a more realistic future scenario is one where not eliminations, but reductions are occurring simultaneously for all causes of death,[41] and they are all influencing lifespan inequality depending on the age of occurrence and its intensity.

Similar to our findings of the gender gap in life expectancy and lifespan disparity, distinct sex difference was also observed in the role of causes of death. Research using historical data from developed countries including the USA, England and Wales, New Zealand, Japan and Sweden has found that in the past century, the major contributor to the sex gap has changed from excess male mortality among infants and young adults to excess mortality associated with CVD in age group 50–70, due to changes in epidemiological context and increased male vulnerability emerged with changes in heart-related behaviour.[42 43] Our analysis shows that in China, CVD still affects the female life expectancy more than the male one, while respiratory diseases, external causes, lung and liver cancers are the causes that have bigger impacts on the life expectancy and lifespan disparities of males than females. The age components of lifespan disparity difference (as shown in online supplemental appendix 4) indicate that external causes severely threat the health of young men and in general working-age males are more threatened than their female counterparts, especially in the rural area, which is not unexpected given men are found to be more exposed to occupational hazard.[44 45] Previous studies have linked the sex differential in mortality caused by respiratory diseases, lung cancer and liver cancer to the high prevalence of smoking and alcohol drinking behaviour among Chinese males, as well as the social norms and stigma against these behaviours of the females.[46 47] Our analysis indicates that this sex differential in deaths from respiratory diseases, external causes, lung and liver cancers also further transforms into a lower dispersion in the female lifespan than in the male lifespan.

Apart from the sex bias, there is also urban–rural bias in how the causes of death impact life expectancy and lifespan disparity in China. We notice that lung and breast cancers have higher impacts over the urban life expectancy and lifespan disparity than over the rural ones, while liver cancer and external causes more heavily affect rural residents. We suspect that this is explained by differences in urban and rural settings such as pollution levels,[48] lifestyle differences[33] on top of other socioeconomic factors.[44] More research on the urban–rural biases

and sex differences would help the professionals working in public health to better target the groups vulnerable to certain diseases and to allocate the resources wisely.

The sudden outbreak of the COVID-19 pandemic has unexpectedly yet severely impacted the public health situation across the globe. Up to 23 October 2021, a total of 109,103 cases have been confirmed in China and 4,849 deaths were identified as COVID-19 deaths.[49] Though detailed information and high-quality data are not yet available for us to analyse how the outbreak of this pandemic has affected health inequality at the subnational level in China, observations and evidence imply that the coronavirus has exerted different levels of impacts across populations with different traits, such as age, gender, geographic location and economic conditions.[50–52] Predicably, pandemics like the COVID-19 would have an important and even long-lasting influence on health inequality within China. Further analysis should be conducted when there are sufficient data and information.

Limitations of this study should be mentioned: the Chinese DSP data are the best source available for cause-of-death analysis, estimation of regional life expectancy and lifespan disparities (especially in non-census years) in China. The under-reporting issue of the data is of particular concern. Although the reliability of data issue was partially mitigated in this study by adjusting the under-reporting among young age groups, there could still be different degrees of death under-reporting across age and sex groups, areas and causes of death. The quality of causes of death statistics in urban and rural China might also not be the same.[53] It is worth noting that in the cause-deleted analysis of this paper, the deaths deleted from one cause are essentially redistributed, but the competing risks of death were not fully adjusted due to the lack of information about multiple causes of death and the causal associations. The assumption that the causes of death are independent of each other might be more problematic for some causes (such as CVD and cancers) than others (such as external causes). Therefore, the results should be interpreted with caution.

As one of the first studies to integrate life expectancy and lifespan disparity in China at the subnational level and to examine the disease-specific contribution behind this, this paper is an attempt to fill the current research gap and provide evidence from China. By using the measure of lifespan disparity and cause-deleted methods, we estimate the level of inequality in the length of life for subpopulations in China, as well as examine the contribution made by different causes of death and how it varies across areas, sexes and age patterns. Future studies may use this research as a stepping stone to make an international comparison, or to further discuss the health inequality in China and how it is shaped by contextual factors on different levels.

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