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### Age-Related Disease Burdens, Disparities, and Health Resource Allocation:
### A Longitudinal Data Analysis of 31 Provinces in Mainland China

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# Age-Related Disease Burdens, Disparities, and Health Resource Allocation: A Longitudinal Data Analysis of 31 Provinces in Mainland China

**Title page**

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**Abstract**

Background

Measuring chronological age alone does not provide sufficient context for understanding the impact of ageing on societal resource planning. The burden of age-related diseases (ARDs) reflects age-related morbidity and mortality at the population level, which unveils the underlying health burden of ageing. The current study aims to measure the ARD burden and its disparities at subnational level of China, a rapidly ageing country with regional imbalances in economic and health development, and assess the impact of health resource allocation on this burden.

Methods

We used the longitudinal data collected from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2016 and 2019 to measure the ARD burden in 31 provinces in mainland China, and from China Statistical and Health Statistical Yearbooks for health resources and socio-economic indicators from 2010 to 2016. We first identified the ARDs, defined as diseases with incidence rates that increased quadratically with age, and calculated the burden as the sum of the disability-adjusted life-years (DALYs) of the ARDs. We further compared the disparities in the ARD burden by province, sex, and disease group, based on the ARD burden of non-communicable diseases (NCDs). The ARD burden-adjusted age for each province was also calculated by assuming each province shared the same age-specific burden rate as the national average. Historical changes in burden between 1990 and 2016 were assessed after standardising the age structure. Total health expenditures per capita, total health professional density, licensed doctor density, and licensed nurse density were used as proxy indicators for health resources. Panel data analysis approach was used to assess the impact of these indicators on the burden of ARDs from 2010 to 2016 based on multivariate regression models.

Findings

NCDs accounted for over 90% of China's total ARD burden in 2019. There were significant regional disparities: the rate of ARD burden was lowest in the south-eastern coast provinces, followed by the central provinces, and trailed by the north-eastern and western provinces. In 2016, the ARD burden-adjusted ages of Shanghai, Beijing, and Zhejiang were the youngest, at 30·86, 30·90 and 36·21 years, respectively. In contrast, the respective ARD burden-adjusted ages of Sichuan, Heilongjiang, and Chongqing were 66·39, 66·14, and 62·98. After standardising the age structure, Tibet, Qinghai, Guizhou, and Xinjiang had the highest burden of ARDs and oldest ARD burden-adjusted age. Males are disproportionately affected by ARDs, with burden rate 70% higher than females. China's overall age-standardised ARD burden has been decreasing since 1990. The largest decline was observed in the eastern provinces, followed by the central and western provinces. However, the burden rate of neurological disorders has continued to increase, albeit only by a small amount. Panel regression results showed increasing either health expenditures or health workforce density could not significantly lower the ARD burden. However, the existing urban-rural gap in health workforce density was positively associated with a consistent increase in the ARD burden. A 100% increase in the urban-rural ratio in total health professional density, licensed doctor density, and licensed nurse density led to 2·55% ($p=0·09$; 95% CI: -0·42, 5·53), 2·29% ($p=0·07$; 95% CI: -0·24, 4·80), and 2.21% ($p=0·08$; 95% CI: -0·31, 4·73) increases in the ARD burden respectively, ceteris paribus.

Interpretation

Older demographic structure does not necessarily mean higher ageing-related health burden. Resource planning for an ageing society should consider the burden of ARDs. In China, concerted efforts should be made to reduce the ARDs burden and its disparities, especially among western provinces which face greatest health threat due to future ageing. Continued investment in health is useful. Particularly, health workforce supply should be deliberately biased toward rural areas in western provinces.

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**Research in context**

**Evidence before this study**

Health is a key factor in determining whether ageing means more opportunities for or challenges to society. To better understand the interactions between health and ageing, two previous studies have used novel metrics to measure China's ARD burden. Chang et al. used the estimates from the 2017 GBD to measure and compare the ARD burden of 195 countries from 1990 to 2017. They identified 92 ARDs, of which 81 are non-communicable diseases (NCDs), and found large disparities in ARD burdens across countries. Chang et al. also found that age-standardised ARD burdens decreased globally between 1990 and 2017. Hu et al. assessed China's ARD burdens based on the 2017 GBD study estimates and consistently found NCDs are the primary contributor to the ARDs. They also found a decrease in age-standardised ARD burdens between 1990 and 2017 in China, with larger magnitude of decrease among women. Several additional studies have been conducted to guide resource planning by assessing the impact of health resource allocation on health outcomes. Research has consistently shown that increasing the health workforce density can help improve health outcomes, while there is mixed evidence regarding the impact of health expenditures per capita on health outcomes.

**Added value of this study**

China is a rapidly ageing country with large economic and health disparities across provinces. The number of people over 60 years old in China was 264 million in 2020, ranking first globally and is estimated to double by 2050. Understanding the ARDs burden, especially the disparities across provinces in China, and the impact of health resources allocation on the burden, is crucial for China's central and provincial governments to understand the health burden brought by ageing. However, no study has yet been conducted to provide such evidence. The current study used longitudinal data from the 2016 and 2019 GBD study to assess ARD burden disparities across provinces, sexes, and disease groups, along with exploring the historical changes that occurred between 1990 and 2016. Using additional data collected from China Statistical and Health Statistical Yearbook in 2010–2016, this study also analysed how health resource allocation impacted the ARD burden. These results provide insights into the relationship between health and ageing and policy implications for health resource planning to decrease ARD burden and foster a healthy ageing society in China. The findings from this research are generalisable to other developing countries with similar demographic challenges and disease profiles.

**Implications of all the available evidence**

Our study provides valuable insights into the disease burden associated with ageing in China. NCDs are the main cause of ARDs in China, and significant regional disparities exist among provinces of different development statuses. Developed provinces such as Shanghai, Beijing and Zhenjiang, had lower burden of ARDs though with older demographic structure. The overall burden has trended downwards since 1990, with the largest declines observed in developed regions. By disease category, however, the burden of neurological disorders has trended upwards since 1990. Compared to females, males continue to bear higher ARD burdens with lower levels of historical decline. Continuing to invest in health and reducing the urban-rural health workforce density gap are effective strategies for reducing the ARD burden.

We challenge the common understanding that regions with higher proportion of older people would suffer from higher age-related disease burden and therefore require more health resources. We argue that policy suggestions based on this understanding will lead to inefficient investment and distribution of resources. This approach is not only useful for analysing China, but also for other countries. China and other ageing countries should act immediately to decrease the ARD burden to support healthy ageing.

## Introduction

The world is rapidly ageing due to increased life expectancy and decreased fertility rates.[1] Health is a key factor in determining whether population ageing means more opportunities or challenges to society.[2] Although the global population is living longer, it is unclear whether these extended years of life are spent in good or bad health.[2–9] It is therefore essential to gain a clearer understanding of the relationship between ageing and health. Numerous metrics have been developed to measure population ageing and health for resource planning. Traditionally, the change of chronological age and age structure have been used to assess ageing based on demographic metrics such as life expectancy or the percentage of the population over a certain age threshold.[10] Another set of metrics assesses functional status through indicators such as frailty,[11,12] disability,[13–15] cognitive function,[16] and intrinsic capacity.[17,18] Health status is typically assessed based on biomarkers, self-reported health status[19,20] and epidemiological indicators of different diseases such as incidence, prevalence, mortality, and disability-adjusted life years (DALYs). Some metrics measure ageing while also taking health status into account. These metrics include healthy life years (HLYs), healthy life expectancy (HALE), and biological age. However, these metrics either measure ageing and health separately or cannot provide disease-specific burden information to guide resource planning.

To complement the existing metrics and measure the population-level interactions of ageing and health, Chang et al. developed a novel metric called the age-related disease (ARD) burden.[21] They defined ARDs as diseases with incidence rates that increased quadratically with age. The researchers used estimates from the 2017 Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) to measure and compare ARD burdens of 195 countries from 1990 to 2017. They identified 92 ARDs, of which 81 are non-communicable diseases (NCDs). The further found large variations in ARD burdens across countries. Of the 195 countries, Switzerland had the lowest ARD burden, while China ranked 75th and Vanuatu had the highest. The researchers found that the age-standardised ARD burden dropped globally between 1990 and 2017 due to lower disease severity and case fatality rates. Hu et al. assessed China's ARD burden in China based on the 2017 GBD study estimates. The researchers consistently found that NCDs are the primary contributor to ARDs in China. The age-standardised ARD burdens also decreased between 1990 and 2017 in China, and the magnitude of ARD decrease was larger among women than men.[22] These findings emphasise the inadequacy of using chronological age alone to inform resource planning and policy design. They confirm the importance of considering health status and disease severity within the context of ageing and the need for concerted efforts to address regional disparities, especially for regions or countries with large development inequalities.[21,22]

Many previous studies have assessed whether and how health resource allocation can impact health outcomes.[23–29] Health workforce density and total health expenditures per capita have been widely used as key proxies for health resources. A large body of high-quality evidence supports that a higher density of health workforce can help improve health outcomes such as life expectancy, infant mortality rate, under-five mortality rate, and maternal mortality rate.[23,24] Evidence further shows heterogeneity among different types of health workforce in terms of how they impact health outcomes.[23,24] The impact of health expenditures on health outcomes is mixed.[26–29] For example, evidence shows that an increase in health expenditures per capita can positively impact health outcomes, including life expectancy, under-five mortality, and maternal mortality in Sub-Saharan African countries,[29] though a similar study did not find supporting evidence in Organisation for Economic Co-operation and Development (OECD) countries.[26] Another study found a significant association between higher health expenditures per capita and lower infant mortality in 15 European Union (EU) countries, but only marginal increases in life expectancy.[28]

China is a large, rapidly ageing country with uneven economic and health development across provinces. In 2020, 264 million of China's inhabitants (18.7%) were over 60 years old, ranking first globally by this metric, and this number is projected to double by 2050.[1,30] Generally, in China, the economy is most developed in eastern provinces followed by the central and western provinces. For example, in 2020, the gross domestic product (GDP) per capita in Shanghai, a municipality located on China's east coast, was 4·3 times higher than that of Gansu, a province in western China.[30] Regional disparities in health development are similar in scale; provinces in the eastern coastal region generally perform best, followed by the central and western provinces.[31] For example, among males in 2015, the average healthy life expectancy was estimated to be around 78 years in Beijing, Tianjin, and Shanghai, compared to 69 years in Qinghai, Tibet, and Yunnan located in western China.[32] China is estimated to attain 12 of the 28 health-related Sustainable Development Goals (SDGs) indicators by 2030, and the country's eastern provinces were estimated to achieve a higher number.[33] Therefore, understanding the disparities across provinces and the impact of health resource allocation on the burden of ARDs is crucial for China's central and provincial governments to plan for an ageing society. Nevertheless, no study has yet been conducted for this purpose. To fill the evidence gap, this study aims to: 1) measure the burden of ARDs in China at the subnational level, examining disparities across provinces, by sex, and by disease group, 2) assess changes in ARD burden from 1990–2016, and 3) explore how health resource allocation impacts the ARD burden.

## Methods

### Overview

This study used estimates from the GBD study to calculate and analyse the ARD burden at the provincial level in China. Constrained by data availability, ARD selection was based on estimates from the GBD 2019 study, and the provincial level analysis of the ARD burden used estimates of non-communicable diseases (NCDs) from the GBD 2016 study. The GBD 2016 study estimates include 328 GBD causes in 195 countries between 1990 and 2016.[34] The GBD 2019 study expanded this to 369 causes in 204 countries from 1990 to 2019.[35] The detailed methodology of the GBD 2016 and 2019 studies has been published elsewhere.[34,36] The GBD study classified the causes of health loss into hierarchical categories with four levels, each with increased specificity.[37] Level One consists of three general causes: communicable diseases, NCDs, and injuries. Levels Two, Three, and Four further divide these causes into subgroups.[37] The data related to provincial health expenditures, human resources for health, and economic and demographic indicators were obtained from China Statistical and Health Statistical Yearbooks, providing data from 2010 to 2016 for regression analysis.

The geographical units of analysis are provincial-level jurisdictions in mainland China, including 22 provinces, five autonomous regions, and four municipalities (hereafter referred to as 31 provinces).[30] This study received ethical approval from the University of South Wales (UNSW) Ethics Committee (HC210794).

### ARD selection and burden measurement

Following the definition developed by Chang et al., ARDs were defined as diseases with incidence rates that increased quadratically with age among the adult population.[21] Our selection focused on GBD Level Three causes, and the detailed selection methods have been published elsewhere.[21] To include a comprehensive list of diseases, we defined the adult population as people aged 15 years and older in the current study.

The ARD burden was measured by calculating the sum of the DALYs of the identified ARDs in the entire population. A DALY is defined as the sum of the years of life lost due to premature mortality and the years lived with a disability due to a disease or health condition. We used the ARD burden rate, measured as DALYs per 100,000 population, for cross-provincial comparisons. We focused on the ARD burden of NCDs for provincial analysis. To explore the burden composition by disease category, the ARD burden of NCDs was further stratified and analysed at the second level of GBD causes and by sex when appropriate. We also calculated the percentage decrease in the ARD burden to assess the historical change and clustered the results by disease category and region for comparative analysis (please see appendix Table S1 for the administrative divisions).

We estimated the ARD burden-adjusted age of each province to facilitate assessments and comparisons across provinces. We first identified the national ARD burden-adjusted age based on its age-specific burden rate. The age with the closest burden rate was set as the ARD burden-adjusted age of the country. Afterwards, the provincial ARD burden-adjusted age was calculated, assuming each province shared the same average age-specific burden rate as the national average (appendix for calculation details). A younger ARD burden-adjusted age, therefore, implied a lower ARD burden.

To compare historical change in the ARD burden, we applied age standardisation to the calculation using the IHME standard population age structure when necessary (appendix Table S2 for the standard population structure).

**Analysing the impact of health resource allocation on the ARD burden**

We explored the impact of health resource allocation on the ARD burden using a panel data analysis approach. All equations were estimated with a log-linear functional form to enable unit-free comparisons of coefficients. To understand the underlying reasons for burden shifts over time, we used the age-standardised ARD burden rate as the dependent variable. Health expenditures and health workforce density were adopted as proxy measures for health resources. Total health expenditure per capita was the key independent variable used to measure health expenditures.[26,27] The key independent variables used to measure health workforce density were three separate sets of indicators: total health professional density, licensed doctor density, and licensed nurse density, all per 1,000 population. Health professionals included licensed doctors (clinical, dental, public health, and traditional Chinese medicine), licensed nurses, pharmacists, clinical laboratory technicians, and radiologists.[38] We chose three sets of indicators to measure human resources for health because 1) together, they accurately represent the distribution of China's health personnel resources; 2) they are widely used in published literature and heterogeneity exists in terms of their impact on health outcomes;[23,24] 3) data stratified by province and by urban and rural areas are available for all three indicators. We ran three separate regression models to include the three health workforce density indicators respectively.

We included GDP per capita, sex, and education as covariates in the regression models to account for the major socio-economic determinants of the population health burden. To account for the large gaps in urban-rural development and health across China, we included the percentage of people residing in urban areas (measure urbanization process) and the ratio of urban-rural health workforce density in the model as covariates. The model also included time dummies (to control period effects), province fixed effects and an error term (see appendix for model details). Standard errors were clustered at the provincial level. Province was the unit of analysis, and a fixed-effects estimator was used to remove the potential endogeneity from time-invariant omitted variables.

Since provincial-level data on health expenditures per capita and health workforce density were only largely available from 2010 onwards, our panel dataset included data from 2010 to 2016. We performed log-linear interpolation to obtain annual estimates of the ARD rate from 2010 to 2016 as the GBD study only provides estimates in five-year intervals.[35] The health expenditures per capita of 2010 are missing for seven provinces: Shanghai, Hainan, Sichuan, Tibet, Shaanxi, Qinghai, and Ningxia. Only Tibet is missing 2011 data. Therefore, after testing the robustness of the linear increase assumption, we imputed the missing data, assuming a linear increase in per capita health expenditures between 2010 and 2016. All analyses were performed in Stata 16·0 (Stata Corp LLP, College Station, TX, USA).

**Role of the funding source**

The funders of the study, the Bill & Melinda Gates Foundation, the UNSW, and the ARC Centre of Excellence in Population Ageing Research (CEPAR), SHARP Fund UNSW (SHARP001), had no role in study design, data collection, data analysis, data interpretation, or manuscript writing. The corresponding author had full access to all study data and decided to submit this manuscript for publication.

## Results

In 2019, among the 169 Level Three GBD causes included in the GBD 2019 study, 58 causes (34·3%) were selected as ARDs in China (Table 1). Nine of the 58 causes were infectious diseases (15·5%), 47 were NCDs (81·0%), and two were injuries (3·5%). Among the 47 level three NCDs, over 70% were neoplasms, cardiovascular diseases (CVDs), chronic respiratory diseases (CRDs), and neurological disorders. The total burden of ARDs in China was 12,801·6 DALYs per 100,000 population, and NCDs accounted for 90·1% of the total burden. Stratified by disease categories within the NCDs, CVDs, neoplasms, CRDs, and neurological disorders had the highest ARD burden rates, accounting for 47·2%, 32·1%, 11·0%, and 6·0% of the country's total ARD burden from NCDs, respectively.

Significant regional differences in ARD burdens existed in China. The south-eastern coast provinces had the lowest crude burden rates, while north-eastern and several western provinces bore the highest ones (Figure 1). In 2016, Shanghai, Beijing, and Guangdong had the three lowest crude burden rates, at 7,116·4, 7,126·0, and 7,208·3 per 100,000 population, respectively. Sichuan and Heilongjiang had the highest crude burden rates at 15,309·3 and 15,251·9 per 100,000 population, respectively. After controlling for age structure, we noted tiered gaps in age-standardized ARD burden among the eastern coast, central, and western provinces. Shanghai, Beijing, Zhejiang, and Jiangsu had the lowest burdens while Tibet, Qinghai, Guizhou, and Xinjiang had the highest burdens. There were salient disparities between the sexes, with age-standardized ARD burden rates being 70% higher among males than females on average. This disparity was most apparent in neoplasms, where the burden rate was 1·4 times higher among males. We observed an inversion of this trend only among neurological disorders, where the burden rate was 20·2% higher among females.

In 2016, China's ARD burden-adjusted age was 50·00 years, and significant disparities existed across provinces (Figure 2). Generally, eastern provinces had the youngest ARD burden-adjusted age, followed by central and western provinces. Specifically, the ARD burden-adjusted ages of Shanghai, Beijing, and Zhejiang were the youngest, at 30·86, 30·90, and 36·21 years, respectively. The ARD burden-adjusted ages of Sichuan, Heilongjiang, and Chongqing were the oldest, at 66·39, 66·14, and 62·98, respectively. After standardising the age structure across provinces, Shanghai, Beijing, and Zhejiang still had the youngest ARD burden-adjusted ages. However, Tibet, Qinghai, and Guizhou became the oldest provinces upon age structure standardisation.

Between 1990 and 2016, China's age-standardised ARD burden decreased despite the increasing life expectancy, with a national average of 36·6% decline compared to the 1990 burden. We found regional disparities in the magnitude of this decline. The largest decline was seen in the eastern provinces, followed by the central and western provinces, with the average ARD burdens declining by 37·5%, 35·8%, and 34·4%, respectively (Figure 3). Breaking this down by province, Fujian experienced the largest decline in ARD burden (44·7%), followed by Zhejiang (44·6%), and Beijing (43·4%). Guangxi, Qinghai, and Guizhou experienced the smallest ARD burden decline in this same period, at 29·6%, 29·0%, 29·0%, respectively. The ARD burden declined more sharply in females (44·1%) than males (31·4%). Between 1990 and 2016, the ARD burden decreased for CVDs, neoplasms, and CRDs but increased for neurological disorders (Figure 4). CRDs experienced the sharpest decline (67·9%), followed by neoplasms (31·2%), and CVDs (26·8%). However, the burden of neurological disorders increased by 5% during the same period.

China's health resources grew between 2010 and 2016. The country's total health expenditures per capita increased from 233·9 USD (exchange rate, 1 USD≈6·37 CNY) in 2010 to 526·2 USD in 2016. The total health professional density (number of total health professionals per 1,000 population) increased by 38·6% from 4·4 in 2010 to 6·1 in 2016. In the same period, the licensed doctor density increased by 27·8%, while the licensed nurse density increased by 66·7% (Table S3).[38,39] We reported the regression results in Table 2. All coefficients of the health resource variables had the expected sign. The model results showed neither higher health expenditures per capita nor higher health workforce density could significantly lead to lower ARD burden, ceteris paribus. However, we found that the existing urban-rural gap in health workforce density was positively associated with the ARD burden, albeit only significant at the 10% level, for all the three indicators. A 100% increase in the urban-rural ratio in total health professional density, licensed doctor density, and licensed nurse density led to 2·55% (p=0·09; 95% CI: -0·42, 5·53), 2·29% (p=0·07; 95% CI: -0·24, 4·80), and 2.21% (p=0·08; 95% CI: -0·31, 4·73) increases in the ARD burden respectively, ceteris paribus.

**Discussion**

Healthy ageing has become a focal discussion topic in today's fast-ageing world, as good health in advanced age can provide continued opportunities for social and personal development.[2] The World Health Organisation officially proposed the concept of healthy ageing in 2015 and published the Global Strategy and Action Plan on Ageing and Health (2016–2020) in 2016. [2,40] The Decade of Healthy Ageing: Plan of Action (2020–2030) was issued in 2020 and asked for a whole-of-government and whole-of-society response to healthy ageing.[41] In response to this international call and the needs of the world's largest ageing population, China has actively worked to address the shifts catalysed by an ageing society and promote healthy ageing.[42–44] We conducted this study to generate high-quality evidence to help China and similar countries be better equipped to face health challenges in ageing societies. To our knowledge, this is the first study that assesses the burden of and longitudinal changes in ARDs at the subnational level of China over 26 years. The analysis explored disparities in ARD burdens across regions, sexes, and disease categories and used panel regression models to examine the impact of health resource indicators on the ARD burden.

Our findings underscore several key messages relevant to health and ageing in China. First, NCDs account for over 90% of the country's total ARD burden. CVDs, neoplasms, CRDs, and neurological disorders were the top four contributors to the ARD burden. Second, there are significant regional disparities in ARD burdens. The results show tiered differences in ARD burden, with the lowest rates in the south-eastern coast provinces, followed by the central provinces, and the highest rates in the north-eastern and western provinces. Notably, the crude ARD burden rate in Sichuan was 2·2 times that of Shanghai in 2016, equal to a 35·53-year gap measured by the ARD burden-adjusted age defined in this study. Third, several western provinces will face daunting ARD-induced challenges as their populations begin to age. After age structure standardisation, Tibet, Qinghai, Guizhou, and Xinjiang had the four highest ARD burdens. However, in 2016, less than 10% of each of these provinces' populations were aged 65 and older, while the national average was 10.8%.[30] Fourth, males are disproportionally affected by ARDs except for neurological disorders. Fifth, the overall age-standardised ARD burden has been decreasing since 1990, though the largest decline was observed in the eastern provinces, followed by the central and western provinces. By disease category, CRDs experienced the largest decline in age-standardised burden, followed by neoplasms and CVDs. The burden rate of neurological disorders has increased since 1990, albeit by a small magnitude. Lastly, our results suggest that greater investment in health to reduce the urban-rural gap in human resources for health could help lower China's ARD burden.

Our study findings are consistent with previous studies that assessed the ARD burden globally and in China using the GBD 2017 study estimates.[21,22] There is overall support for the idea that NCDs are the chief contributor to ARDs, accounting for over 90% of the total ARD burden. As has been the case across the globe, the ARD burden has continuously decreased since 1990, declining most sharply in developed countries and regions. Disparities by sex are also similar; males are more negatively affected by ARD burden and have experienced a lower historical decline. The magnitude of the burden measured in this study is slightly different than those in other studies due to differences across GBD datasets and the populations and diseases included. Our findings are novel in that we were able to measure the ARD burden and disparities across provinces in China. Nevertheless, the regional disparities of age-standardised ARD burdens are in line with their health development status and similar to the disparities in estimated healthy life expectancy.[45–33] The rank of NCD burdens among the ARDs is consistent with that of the disease burden among older people in China.[46] Interestingly, we found that increasing health expenditures or workforce density does not significantly decrease ARD burden; rather, the key is to reduce the urban-rural gap in the health workforce density. Previous evidence has indicated that increasing health workforce density can improve health outcomes.[23,24] However, these studies focus on measuring health outcomes such as maternal mortality, infant, and under-five mortality as opposed to ageing-related outcomes. In addition, these studies did not control for geographic resource differences between rural and urban areas and were conducted in countries where resources were scarce. Thus, the context was quite different from that of the present study.

The Chinese State Council published *The Opinions on Strengthening Aged Care Work in the New Era* in November 2021, outlining eight important action domains for addressing ageing. This document serves as a comprehensive, strategic plan to achieve healthy and active ageing in China.[44] The findings from the current study provide timely policy implications for the governments of China to promote healthy ageing by reducing the ARD burden. First, to reiterate the findings from previous studies, chronological age alone does not provide a strong enough basis for appropriate ageing resource planning or policymaking.[21,22] In China, provinces or municipalities with older populations, such as Shanghai, Beijing, and Zhejiang, have much lower ARD burdens than some younger provinces such as Tibet and Xinjiang. This phenomenon calls for more careful consideration of underlying health burdens and potential threats to resource planning and policy design to address future ageing. Second, it is crucial to continue and strengthen NCD prevention and control efforts, especially for CVDs, neoplasms, CRDs, and neurological disorders. To prevent the continued increase in the ARD burden from neurological disorders, it is imperative to allocate additional health resources for the prevention, treatment, and management of conditions such as Alzheimer's disease, dementia, Parkinson's disease, and idiopathic epilepsy. Third, the central government should continue providing all-around support to the regions that face the greatest threat of high ADR burdens due to future ageing, especially the western provinces of Tibet, Qinghai, Guizhou, and Xinjiang to reduce regional disparities. Notably, the support should entail the establishment of a strong health workforce that can serve the local people. Fourth, aligned with the Rural Revitalization Strategic Plan issued by the State Council (2018–2022) in 2018,[47] both central and local governments should work collaboratively to strengthen the health system in rural areas, particularly increasing the health workforce density to reduce the urban-rural gap.

Our study has several limitations. First, the subnational analysis was based on the GBD 2016 study estimates. It was not the most up-to-date GBD data set, though this was the best data source we could access. Second, our provincial analysis of the ARD burden focused on NCDs due to data availability. However, as NCDs accounted for over 90% of the ARD burden, these results still accurately represent existing regional disparities. Third, the study findings tend to underestimate the ARD burden, as GBD study estimates fail to model the interactions between diseases, ignoring the burden caused by multimorbidity. Fourth, we had to rely on interpolation to obtain annual estimates of burden rates from 2010 to 2016 for panel data analysis, though the GBD research team used the same methods in their analysis.[35] In addition, the indicators to measure health resources limit to total health expenditures and health workforce density, largely due to data availability. Other important indicators, such as efficiency of health funds utilization, quality of human resources for health, could be explored in future research when data become available.

**Conclusion**

In conclusion, our study provides valuable insights into the disease burden associated with ageing in China. Our results consistently show that older demographic structure does not necessarily mean heavier health burden, and therefore chronological age alone does not provide a strong enough basis for appropriate ageing resource planning or policymaking. Continuing to invest in population health through reducing the urban-rural gap in health workforce density are helpful to decrease the ARD burden in China. The governments of China, or other countries with similar demographic and disease profiles and development contexts, need to take urgent action to decrease the burden of ARDs to create healthy ageing societies.

**Contributors**

SC designed the study under the supervision of KH, BL, and HB. SC extracted the data, conducted the statistical analysis in Stata, drew the tables and figures, and drafted the manuscript. SC and YS verified the data in the study. ST obtained the GBD data. All authors contributed to commenting, editing, and approval of the final manuscript. All accept responsibility to submit for publication.

**Declaration of interests**

All co-authors declare no conflicts of interest for this study.

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**Data sharing**

China's subnational-level data from GBD 2016 were obtained from the IHME under a private agreement. Researchers can apply for data access at https://www.healthdata.org/about/contact-us if interested in using the data. Other inputs data were obtained from open resources, including China Statistical Yearbook (http://www.stats.gov.cn/tjsj/ndsj/) and China Health Statistical Yearbook (http://www.nhc.gov.cn/wjw/tjnj/list.shtml). Researchers can access and download the data from these websites.

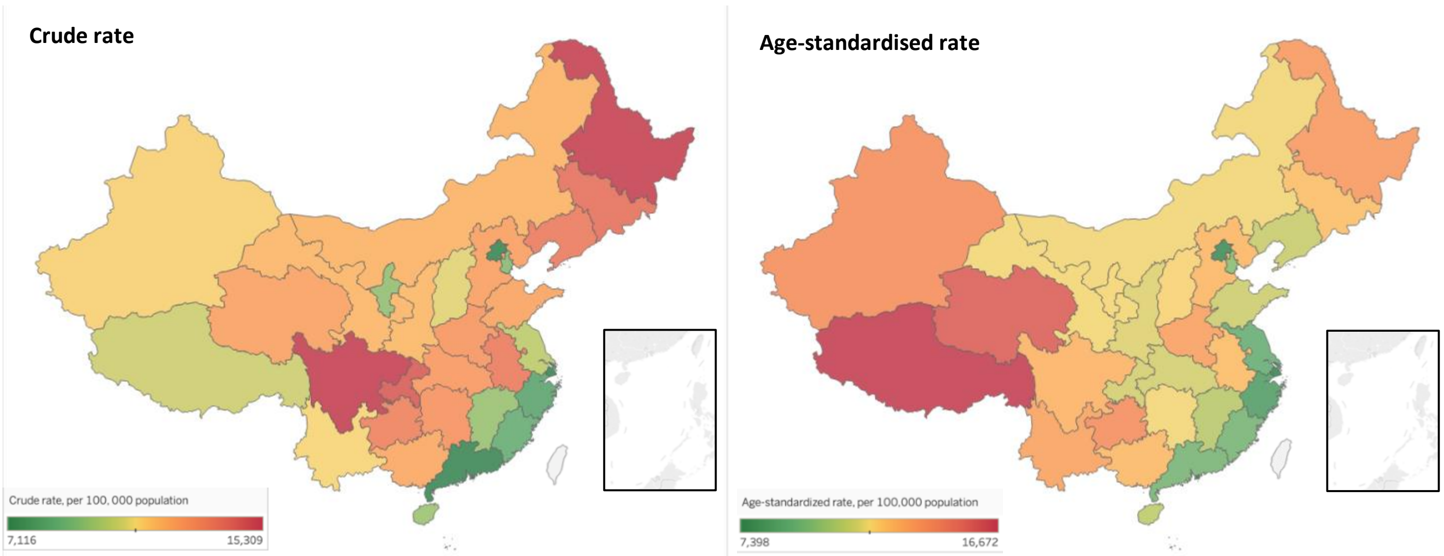
## Tables and Figures

### Table 1. Summary of age-related diseases in China by category

| GBD Causes at Level 1 | GBD Causes at Level 2 | GBD Causes at Level 3 |
|---|---|---|
| **Infectious diseases** | Respiratory infections and Tuberculosis | Tuberculosis, diarrheal diseases, lower respiratory diseases |
| | Other infectious diseases | Meningitis, encephalitis, tetanus, varicella, and herpes zoster |
| | Neglected tropical diseases and malaria | Cysticercosis, trachoma |
| **NCDs** | Neoplasms | Oesophageal cancer, stomach cancer, liver cancer, tracheal, bronchus, and lung cancer, prostate cancer, colon and rectum cancer, lip and oral cavity cancer, other pharynx cancer, gallbladder and biliary tract cancer, pancreatic cancer, malignant skin melanoma, non-melanoma skin cancer, bladder cancer, brain and central nervous system cancer, mesothelioma, Hodgkin lymphoma, non-Hodgkin lymphoma, multiple myeloma, leukaemia, other malignant neoplasms |
| | Cardiovascular Diseases | Ischemic heart disease, stroke, hypertensive heart disease, cardiomyopathy, myocarditis, atrial fibrillation and flutter, peripheral artery disease, endocarditis |
| | Chronic respiratory diseases | Chronic obstructive pulmonary disease, asthma, and interstitial lung disease |
| | Digestive Diseases | Paralytic ileus and intestinal obstruct, vascular intestinal disorders, pancreatitis |
| | Neurological disorders | Alzheimer's disease and other dementias, Parkinson's disease, idiopathic epilepsy, other neurological disorders |
| | Diabetes and kidney diseases | Acute glomerulonephritis, chronic kidney disease |
| | Skin and subcutaneous diseases | Fungal skin diseases, pruritus, decubitus ulcer, and other skin and subcutaneous diseases |
| | Sense organ diseases | Age-related and other hearing loss, other sense organ diseases, blindness, and vision loss |
| | Musculoskeletal disorders | Low back pain |
| **Injuries** | Unintentional injuries | Falls, drowning |

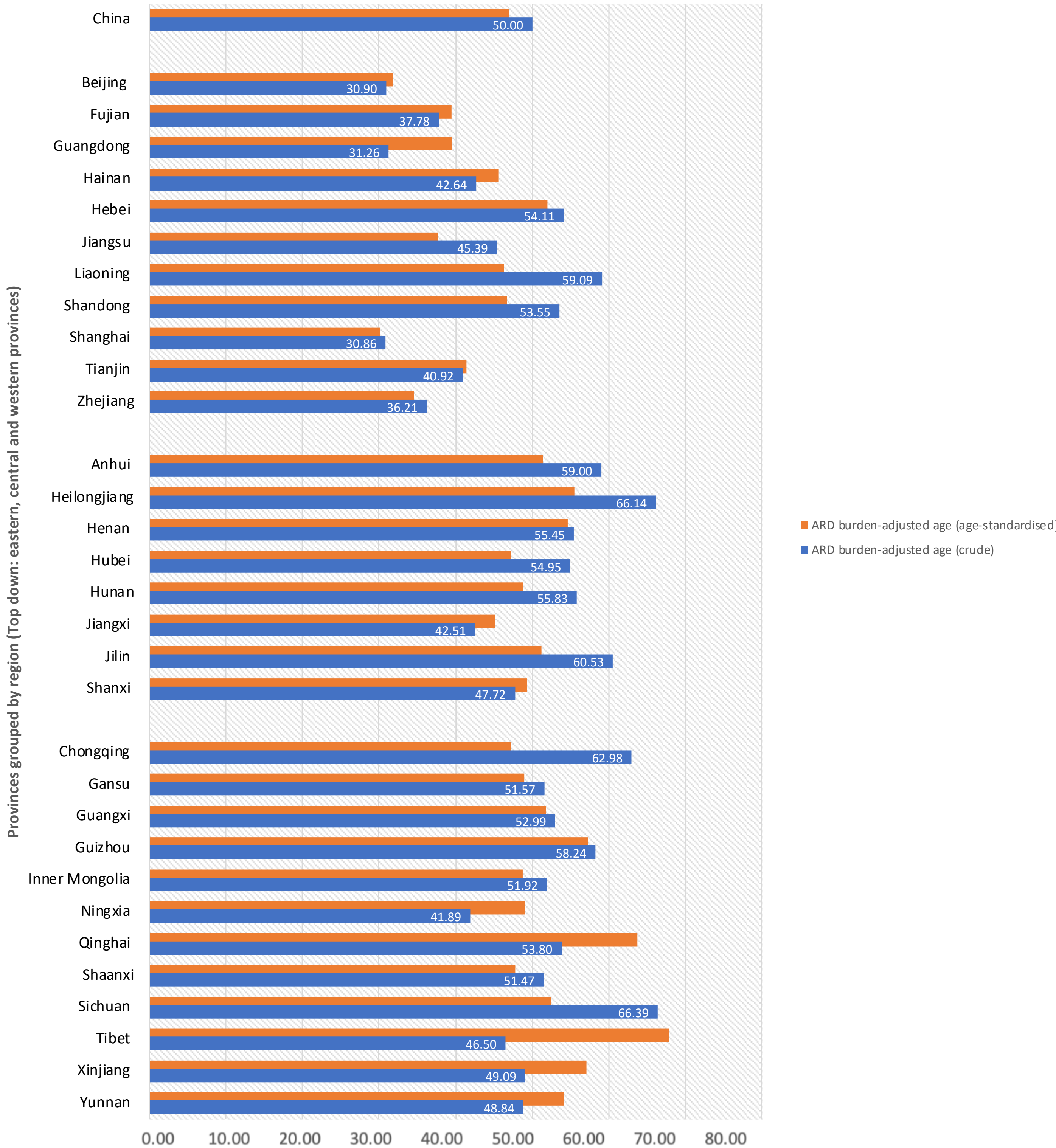
Data source: GBD (2019)

**Figure 1. The age-related diseases burden in mainland China, 2016**




Data source: GBD (2016)
Note: The age-related diseases burden was standardised using the IHME standard population age structure (appendix)

**Figure 2. The age-related diseases burden-adjusted ages of 31 provinces in mainland China, 2016**

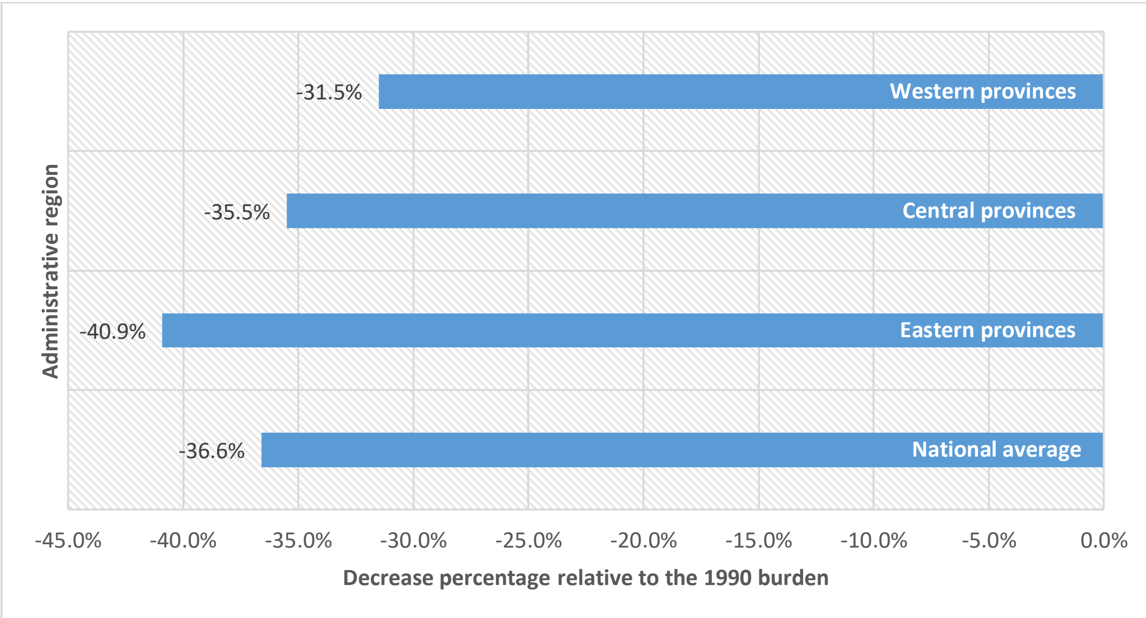



Data source: GBD 2016

Note: The provinces are grouped into eastern, central and western provinces from top down.

The age-related diseases burden was standardized using the IHME standard population age structure (appendix)

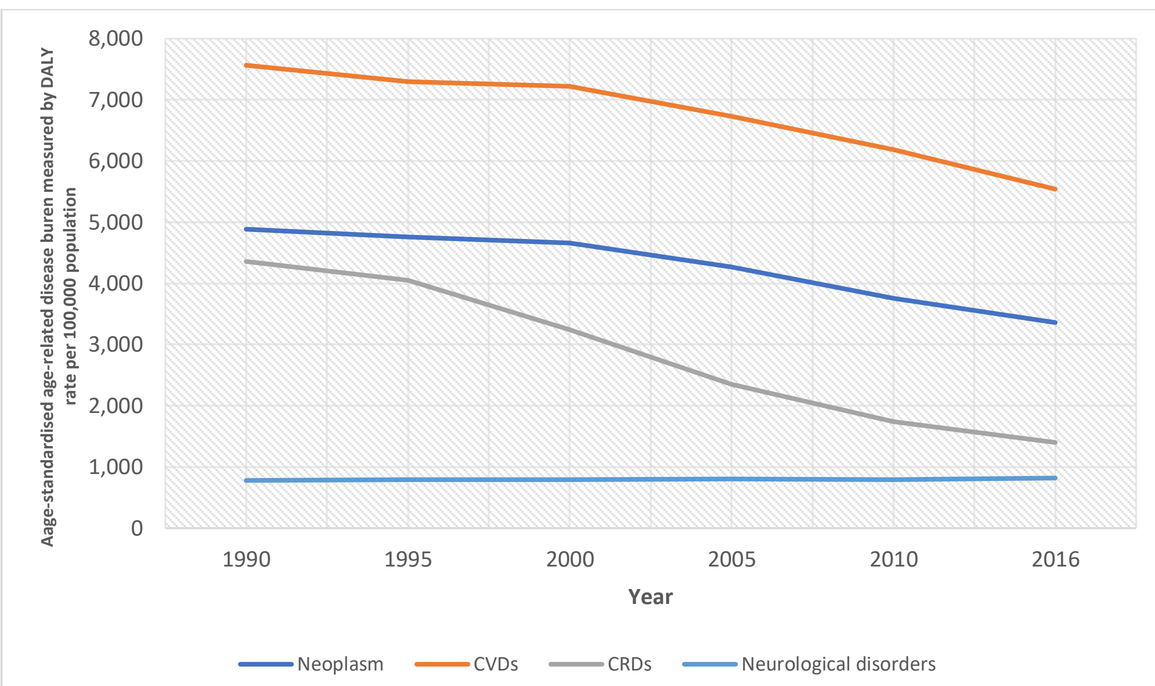
**Figure 3. Change of the age-related diseases burden rates (age-standardised) by administrative region in mainland China, 1990–2016**




Data source: GBD 2016

Note: The age-related diseases burden was standardized using the IHME standard population age structure

**Figure 4. Change of the age-related diseases burden rates (age-standardised) in China by disease category, 1990–2016**




Data source: GBD 2016

Note: The age-related diseases burden was standardized using the IHME standard population age structure (appendix)

**Table 2. Regression model results: Assessing the impact of health resources on age-standardised ARD burden in mainland China, 2010–2016**

| Independent Variables | Model 1 (Total health professional density) | | Model 2 (Licensed doctor density) | | Model 3 (Licensed nurse density) | |
|---|---|---|---|---|---|---|
| | Coefficient (β) | 95% CI | Coefficient (β) | 95% CI | Coefficient (β) | 95% CI |
| Total health expenditures per capita | -2.63 | (-7.14, 1.89) | -2.34 | (-6.83, 2.15) | -2.67 | (-7.25, 1.90) |
| Health professional density | -1.38 | (-1.20, 1.16) | .. | .. | .. | .. |
| Health professional density: urban-rural ratio | 2.56* | (-0.43, 5.53) | .. | .. | .. | .. |
| Licensed doctor density | .. | .. | -0.97 | (-3.50, 1.55) | .. | .. |
| Licensed doctor density: urban-rural ratio | .. | .. | 2.29* | (-0.24, 4.81) | .. | .. |
| Licensed nurse density | .. | .. | .. | .. | -1.41 | (-3.84, 1.03) |
| Licensed nurse density: urban-rural ratio | .. | .. | .. | .. | 2.21* | (-0.31, 4.73) |
| GDP per capita | -0.37 | (-5.64, 4.91) | -1.25 | (-6.97, 4.46) | -0.53 | (-6.12, 5.05) |
| Population living in urban areas (%) | 2.30 | (-16.40, 20.99) | 2.40 | (-15.77, 20.57) | 3.67 | (-15.65, 22.98) |
| Female (%) | -0.50 | (-2.507, 1.506) | -0.79 | (-2.66, 1.09) | -0.75 | (-2.81, 1.32) |
| ≥ junior middle school education (%) | 3.59 | (-1.738, 8.916) | 2.57 | (-2.38, 7.51) | 3.36 | (-1.81, 8.53) |
| _cons | 9.73*** | (8.92, 10.55) | 9.79*** | (8.95, 10.63) | 9.74*** | (8.90, 10.58) |
| adj. $R^2$ | 0.93 | .. | 0.93 | .. | 0.93 | .. |

Data sources: GBD (2016,), Statistical Yearbook of China (2011–2017), and the Health Statistical Yearbook of China (2011–2017)

Notes:
All dependent and independent variables were transformed into natural logarithms for regressions except for the time dummies. The independent variables of interest and covariates were rescaled by divided by 100. The coefficients can be interpreted as follows: every 100% increase in X can lead to a β% increase on Y.
Model 1 used total health professional density (per 1,000 population) as a proxy for human resources for health.
Model 2 used licensed doctor density as a proxy (per 1,000 population) for human resources for health.
Model 3 used licensed nurse density as a proxy (per 1,000 population) for human resources for health.
Significance level: *(p<0·10); **(p<0·05); ***(p<0·01)

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## Appendix

**Table S1. Administrative division of provinces in mainland China**

| Administrative division (No.) | Province |
|---|---|
| Eastern provinces (11) | Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong Shanghai, Tianjin, Zhejiang |
| Central provinces (8) | Anhui, Heilongjiang, Henan, Hubei, Hunan, Jiangxi, Jilin, Shanxi |
| Western provinces (12) | Inner Mongolia, Guangxi, Chongqing, Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Sichuan, Tibet, Xinjiang, Yunnan |

**Table S2. IHME standard age weight**

| Age group | Population percentage |
|---|---|
| <5 | 7.2% |
| 5–9 | 8.7% |
| 10–14 | 8.4% |
| 15–19 | 8.1% |
| 20–24 | 7.8% |
| 25–29 | 7.6% |
| 30–34 | 7.2% |
| 35–39 | 6.9% |
| 40–44 | 6.4% |
| 45–49 | 5.8% |
| 50–54 | 5.3% |
| 55–59 | 4.7% |
| 60–64 | 4.1% |
| 65–69 | 3.4% |
| 70 + | 8.6% |

### ARD burden-adjusted age calculation

First, we identified the ARD burden-adjusted age of China as a whole by comparing the national average burden rate with its burden rates by age group. The age with the closest burden rate was set as the ARD burden-adjusted age of the country. For example, the age-related disease burden of China was 11,530·5 DALYs per 100,000 population in 2016, closest to the averages of the 45–49 and 50–54 burden rates. Therefore, we set the national average age to 50 years old.

Second, we calculated the ARD burden-adjusted age of each province by dividing the provincial age-related disease burden rate by the unit share of the age-specific national average burden rate. The unit share of the age-specific national average burden rate was calculated by dividing the national average burden rate by the national equivalent age. For example, the age-related disease burden of Shanghai was 7,116·4 DALYs per 100,000 population. Its ARD burden-adjusted age is 7,116·4/(11,530·5/50)=30·86.

**Regression model**

$$Y_{it} = \alpha + \beta_0 healthexp_{it} + \beta_1 healthwf_{it} + \beta_2 X_{it} + \beta_3 D_t + \eta_i + \varepsilon_{it},$$

where $Y_{it}$ is the age-standardised age-related disease burden of Province $i$ in Year $t$, $\beta_0$ is the coefficient of interest, $healthexp_{it}$ is the total health expenditures per capita, and $healthwf_{it}$ is the total health professional density, licensed doctor density, or licensed nurse density (per 1,000 population) of the Province $i$ in Year $t$ (three separate models). $X_{it}$ is the set of covariates controlled in the model, including GDP per capita, education, the proportion of females, the proportion of people living in urban areas, and the urban-rural health workforce density ratio. $D_t$ represents the time dummies, $\eta_i$ the province fixed effects, and $\varepsilon_{it}$ is the error term. All variables are in log form except for the time dummies.

**Table S3. Selected statistics of the variables in the regression model, 2010 and 2016**

| Variables | Health expenditures per capita (CNY)* | | Total health professionals density (per 1,000 population) | | Urban-rural ratio in total health professionals density | | GDP per capita (CNY)* | | Living in urban areas (%) | | Female (%) | | Received at least middle school education (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Province | 2010 | 2016 | 2010 | 2016 | 2010 | 2016 | 2010 | 2016 | 2010 | 2016 | 2010 | 2016 | 2010 | 2016 |
| Anhui | 1210·5 | 2652·17 | 3·1 | 4·7 | 2·4 | 2·3 | 20888·0 | 39561·0 | 44.8% | 52.0% | 49·2% | 48·7% | 62·8% | 65·5% |
| Beijing | 4147·2 | 9429·73 | 13·6 | 10·8 | 1·9 | ·· | 73856·0 | 118198·0 | 86.2% | 86.5% | 48·4% | 48·6% | 87·6% | 88·6% |
| Chongqing | 1501·0 | 3492·19 | 3·4 | 5·9 | 1·4 | 2·0 | 27596·0 | 58502·0 | 55.0% | 62.6% | 49·4% | 49·2% | 61·0% | 64·1% |
| Fujian | 1280·1 | 3226·83 | 4·1 | 5·7 | 2·8 | 2·5 | 40025·0 | 74707·0 | 58.1% | 63.6% | 48·6% | 49·1% | 63·0% | 61·7% |
| Gansu | 1153·9 | 2889·18 | 3·7 | 5·2 | 2·0 | 2·2 | 16113·0 | 27643·0 | 37.2% | 44.7% | 48·9% | 49·3% | 56·5% | 57·9% |
| Guangdong | 1445·9 | 3812·46 | 5·3 | 6·0 | 3·2 | 3·2 | 44736·0 | 74016·0 | 66.5% | 69.2% | 47·8% | 46·9% | 73·2% | 74·3% |
| Guangxi | 1116·9 | 2557·03 | 3·6 | 6·0 | 2·2 | 2·2 | 20219·0 | 38027·0 | 41.8% | 48.1% | 48·0% | 48·0% | 62·5% | 67·4% |
| Guizhou | 946·6 | 2472·37 | 2·5 | 5·8 | 4·2 | 3·9 | 13119·0 | 33246·0 | 35.0% | 44.2% | 48·3% | 48·4% | 48·8% | 54·6% |
| Hainan | 1193·0 | 3306·78 | 4·4 | 6·3 | 2·3 | 3·3 | 23831·0 | 44347·0 | 50.5% | 56.8% | 47·4% | 47·3% | 72·1% | 73·0% |
| Hebei | 1253·8 | 2710·58 | 4·0 | 5·3 | 3·2 | 2·7 | 28668·0 | 43062·0 | 45.6% | 53.3% | 49·3% | 48·9% | 69·9% | 69·7% |
| Heilongjiang | 1580·2 | 3133·43 | 5·0 | 5·8 | 2·3 | 2·3 | 27076·0 | 40432·0 | 56.5% | 59.2% | 49·2% | 49·5% | 73·0% | 73·3% |
| Henan | 1134·0 | 2594·0 | 3·5 | 5·7 | 3·0 | 3·2 | 24446·0 | 42575·0 | 40.6% | 48.5% | 49·5% | 49·0% | 68·2% | 69·8% |
| Hubei | 1191·1 | 3270·56 | 4·2 | 6·5 | 2·1 | 2·2 | 27906·0 | 55665·0 | 51.8% | 58.1% | 48·6% | 48·7% | 69·8% | 70·5% |
| Hunan | 1042·1 | 2820·97 | 3·8 | 5·8 | 2·9 | 2·9 | 24719·0 | 46382·0 | 45.1% | 52.8% | 48·6% | 48·9% | 67·1% | 71·2% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inner Mongolia | 1767·5 | 3599·7 | 5·1 | 6·8 | 2·7 | 2·6 | 47347·0 | 72064·0 | 56.6% | 61.2% | 48·1% | 49·5% | 69·9% | 73·3% |
| Jiangsu | 1566·0 | 4200·21 | 4·4 | 6·5 | 2·0 | 2·1 | 52840·0 | 96887·0 | 61.9% | 67.7% | 49·6% | 49·6% | 70·9% | 71·5% |
| Jiangxi | 992·0 | 2374·79 | 5·1 | 6·1 | 1·8 | 2·1 | 21253·0 | 40400·0 | 45.7% | 53.1% | 48·2% | 48·0% | 65·6% | 64·1% |
| Jilin | 1653·9 | 3501·19 | 5·5 | 6·3 | 2·5 | 2·9 | 31599·0 | 53868·0 | 53.4% | 56.0% | 49·3% | 49·2% | 69·8% | 73·6% |
| Liaoning | 1765·9 | 3390·9 | 4·7 | 6·6 | 3·0 | 2·6 | 42355·0 | 50791·0 | 64.0% | 67.4% | 49·4% | 49·5% | 75·5% | 78·3% |
| Ningxia | 1190·1 | 3730·50 | 4·5 | 6·2 | 4·4 | 5·4 | 26860·0 | 47194·0 | 49.8% | 56.3% | 48·8% | 48·4% | 61·3% | 66·5% |
| Qinghai | 1472·0 | 4043·05 | 4·7 | 7·6 | 2·0 | 2·0 | 24115·0 | 43531·0 | 46.3% | 51.6% | 48·2% | 48·6% | 49·8% | 51·8% |
| Shaanxi | 2040·7 | 3535·66 | 4·7 | 6·5 | 1·7 | 2·2 | 27133·0 | 51015·0 | 47.3% | 55.3% | 48·3% | 49·5% | 69·8% | 71·5% |
| Shandong | 1403·1 | 3372·70 | 9·7 | 7·4 | 1·3 | 1·6 | 41106·0 | 68733·0 | 50.9% | 59.0% | 49·4% | 49·0% | 67·5% | 69·0% |
| Shanghai | 2828·1 | 7596·0 | 5·6 | 6·1 | 2·6 | 3·2 | 76074·0 | 116562·0 | 89.3% | 87.9% | 48·5% | 48·6% | 83·6% | 83·5% |
| Shanxi | 1297·5 | 2650·33 | 3·4 | 4·8 | 2·7 | 3·0 | 26283·0 | 35532·0 | 49.7% | 56.2% | 48·6% | 48·5% | 74·1% | 77·5% |
| Sichuan | 1019·1 | 3238·64 | 3·6 | 6·0 | 2·0 | 2·0 | 21182·0 | 40003·0 | 41.8% | 49.2% | 49·2% | 50·1% | 57·2% | 58·9% |
| Tianjin | 2737·3 | 5294·21 | 7·1 | 6·1 | 1·4 | 1·1 | 72994·0 | 115053·0 | 80.5% | 82.9% | 46·6% | 46·6% | 80·5% | 82·0% |
| Tibet | 1472·0 | 3780·9 | 3·4 | 4·5 | 4·9 | 4·1 | 17027·0 | 35184·0 | 22.8% | 29.6% | 48·6% | 49·5% | 26·4% | 29·6% |
| Xinjiang | 1676·8 | 4012·9 | 5·7 | 7·1 | 3·2 | 2·4 | 25034·0 | 40564·0 | 43.5% | 48.3% | 48·7% | 48·9% | 66·1% | 65·5% |
| Yunnan | 1107·2 | 2754·1 | 3·2 | 5·2 | 3·2 | 3·3 | 15752·0 | 31093·0 | 36.8% | 45.0% | 48·1% | 49·5% | 48·3% | 52·5% |
| Zhejiang | 2099·0 | 4603·84 | 6·1 | 7·7 | 1·8 | 1·8 | 51711·0 | 84916·0 | 62.3% | 67.0% | 48·6% | 47·9% | 64·7% | 66·0% |

*CNY=Chinese Yuan, exchange rate: 1USD≈6.37CNY (Dec 3, 2020)

Data source: National Statistical Yearbook of China (2011, 2017) and National Health Statistical Yearbook of China (2011,2017)