The Dynamics of Estimated Health Burdens Due to Air Pollution Exposure – A Case Study in China

by

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Introduction

Unlike stratosphere ozone (O_3) located in the ozone layer which prevents people from getting harmful ultraviolet radiation, ground-level ozone can be detrimental to buildings, agricultural crops and human health (EPA, 2013). Specifically, ozone can lead to a set of non-communicable diseases, such as COPD (Chronic Obstructive Pulmonary Disease) and cardiovascular diseases (Jerrett *et al.*, 2009; Lipsett *et al.*, 2011; Turner *et al.*, 2016). A recent study using measurement-based assessment estimated 200K premature respiratory mortalities and 129K premature cardiovascular mortalities attributable to long-term ozone exposure in China during 2015, which are much higher compare to Europe (34K respiratory mortalities and 17K cardiovascular mortalities) and USA (32K respiratory mortalities and 24K cardiovascular mortalities (Seltzer *et al.*, 2018). Even though new emission control efforts have been undertaken to reduce air pollution after the first amendment to China's environmental protection law which took effect in 2015, the task of reducing air pollution-induced health burdens still becomes increasingly difficult due to the population aging.

Figure 1 below visualized the trend of China's age structure change from 1980 to 2015 in a clear way: China's elderly population group (above 60) has increased from 7.78% in 1980 to 13.6% in 2015. Meanwhile, we can see a "shift" of the population structure from a young-population (age 10-24) dominated to an elderly-population (age 40-64) dominated structure. The rapid population aging trend is a result of the decline in the fertility rate, age-specific mortality rates and increase in overall life-expectancy.

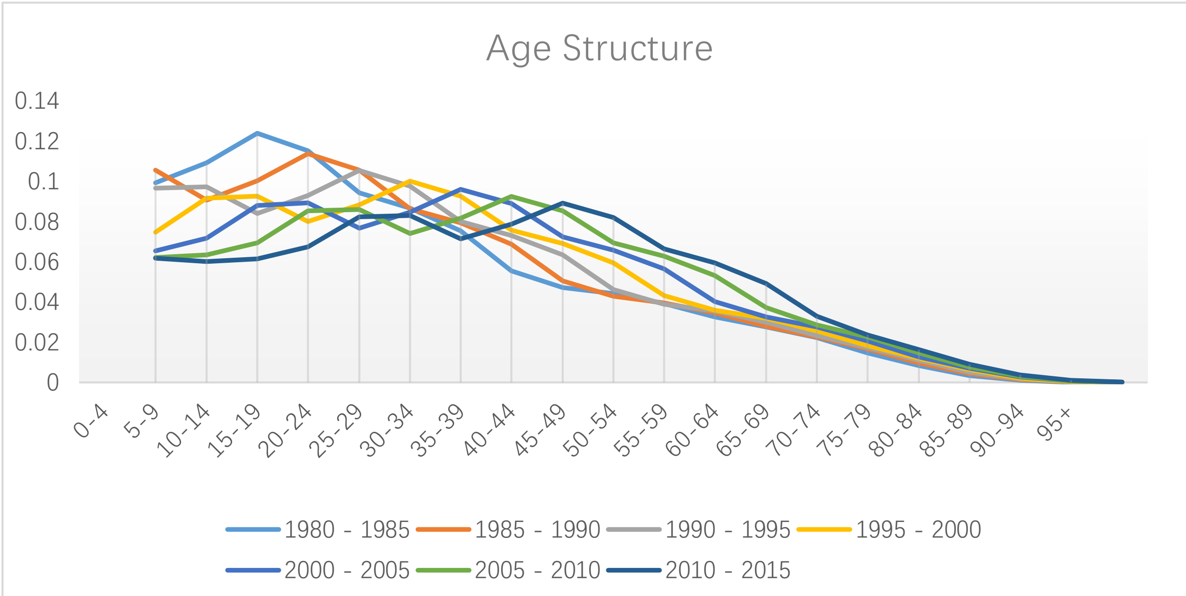

Figure 1 – China's Age Structure Change, 1980-2015, United Nations

In general, when 10% of the population is over 60 years of age or the proportion of the population over 65 years old reaches 7% the society is defined as an aging society (United Nations, 1956). In 2000, China's population aged 60 and over accounted for 10.3% of the total population, marking that China has entered an aging period. In 2000, the number of elderly people aged 65 and over in China was 88.2 million, accounting for 6.9% of the total population. By the year 2015, the number of people aged 65 and over reached 138.5 million, accounting for 10.1% of the total population. The crude death rate in China from 1980-1985 to 2010-2015 increased by 6.01% (0.397 death per 1000 people). While China's economy grew over the past several decades which brings better medical services, we know the population is also rapidly aging. How much of the increase is due to the population composition change and how much is driven by the ASMR (Age Specific Mortality Rate) change? Table 1 below decomposed the crude death rate change. As a result, age composition (population aging) contributes to 0.003549 increase while the ASMR contributes to -0.003151 decrease of the difference in the crude death rate from 1980-2015. When taking the absolute values of the differences, the age composition change contributes to about 53% increase in magnitude while the ASMR change only contributes a decrease of 47%.

Age Group	C 2010-2015 (A)	C 1980-1985 (B)	M 2010-2015 (C)	M 1980-1985 (D)	(A-B)*[(C+D)/2]	(C-D)*[(A+B)/2]
0-4	0.0618	0.0993	0.0029	0.0120	-0.00028	-0.00073
5-9	0.0602	0.1092	0.0003	0.0013	-0.00004	-0.00007
10-14	0.0614	0.1238	0.0002	0.0006	-0.00002	-0.00003
15-19	0.0672	0.1150	0.0003	0.0008	-0.00002	-0.00004
20-24	0.0824	0.0942	0.0005	0.0010	-0.00000	-0.00004
25-29	0.0831	0.0865	0.0007	0.0012	-0.00000	-0.00004
30-34	0.0714	0.0752	0.0009	0.0015	-0.00000	-0.00004
35-39	0.0788	0.0554	0.0011	0.0020	0.00003	-0.00005
40-44	0.0891	0.0472	0.0016	0.0028	0.00009	-0.00008
45-49	0.0821	0.0442	0.0024	0.0041	0.00012	-0.00011
50-54	0.0663	0.0390	0.0040	0.0072	0.00015	-0.00016
55-59	0.0593	0.0327	0.0068	0.0113	0.00024	-0.00020
60-64	0.0491	0.0277	0.0128	0.0198	0.00035	-0.00027
65-69	0.0330	0.0221	0.0232	0.0313	0.00029	-0.00022
70-74	0.0236	0.0147	0.0424	0.0562	0.00043	-0.00026
75-79	0.0164	0.0082	0.0708	0.0929	0.00066	-0.00027
80-84	0.0090	0.0035	0.1078	0.1510	0.00071	-0.00027
85-89	0.0036	0.0010	0.1662	0.2257	0.00051	-0.00014
90-94	0.0010	0.0001	0.2347	0.3147	0.00024	-0.00005
95+	0.0002	0.00002	0.3219	0.4166	0.00007	-0.00001
SUM	1	1			0.003549	-0.003151

Table 1 - Mortality Rate Decomposition of China, 1980-1985 and 2010-2015. United Nations
C: portion in age categories, M: mortality rate

By decomposing the differences of crude death rate, when found that the population aging contributes a significant increase in the overall crude death rate and the decrease in ASMR offsets most of the difference and we found a sign of rapid population aging. Several studies have summarized the trends of global health burdens from air pollution exposure in the past several decades and for the future using different models (Liu *et al.*, 2017; Silva *et al.*, 2016). However, few studies have explicitly attributed trends in health burden estimates to each of the driving factors: pollution exposure, age demographics, and changing baseline mortality rates. A recent study did show that in many Asian countries, especially in Japan, the estimated mortality burden has largely been driven by an aging population over the past 25 years (Cohen *et al.*, 2017). No studies to date have used this analytical approach to assess drivers of future health burdens. Projected trends in China include a continued increase of long-term O_3 exposure, an aging population, and stabilization of baseline mortality rates. This study will analyze the contribution of all of these trends on both the magnitude of health burden estimates from respiratory diseases and cardiovascular diseases.

Methods

In this project we set the population, disease-specific mortality rates and population weighted ground ozone concentration in China at year 2015 as the baseline. 45.3 ppb was selected for China annual average of the maximum daily 8 h average (MDA8) O_3 concentration, and 38.1 ppb was selected for the U.S. MDA8 O_3 concentration based on previous research (Seltzer *et al.*, 2018). Seltzer *et al.*, 2018 used data exclusively from ground-based monitoring stations in China along with an objective-mapping algorithm to estimate a population weighted ozone concentration with 99% of the population captured. Meanwhile, (Turner *et al.*, 2016) have shown that there is a linkage between incremental ozone exposure levels and premature death based on Cancer Prevention Study II from 1982 to 2004 with 669046 participants (ranged from age 30 to age 80+), especially for respiratory and cardiovascular disease. We utilized a respiratory disease mortality hazard ratio of 1.12 (95% CI: 1.08, 1.16) and a cardiovascular hazard ratio of 1.03 (95% CI: 1.01, 1.05).

We summarized methods to calculate the premature deaths attributable to long-term ozone exposure based on threshold models as there is evidence showing model performance improvements compare to models without thresholds (Seltzer *et al.*, 2018; Anenberg *et al.*, 2010).

$$\Delta X = \begin{cases} 0 & if\ [O_3] \leq TMREL \\ [O_3] - TMREL & if\ [O_3] > TMREL \end{cases}$$

$$HR = e^{\beta \Delta Y}$$

$$AF = \frac{HR - 1}{HR} = 1 - e^{-\beta \Delta X}$$

$$\Delta Mort = y_0\left(1 - e^{\beta \Delta X}\right)Pop.$$

where TMREL represents the theoretical minimum risk exposure level (empirical from the epidemiology studies), ΔX is the O_3 population weighted ozone exposure above TMREL, β is the exposure-concentration response factor, HR is the hazard ratio found in relevant epidemiology study which use ΔY, a 10 ppb value that links the change in cause-specific mortality rates to incremental ozone exposure, AF stands for the attributable fraction of the disease specific mortality attributable to a certain air pollutant (here the pollutant is ozone), $\Delta Mort$ is the estimated cause specific premature mortality, y_0 is the cause-specific baseline mortality and Pop. is the population studied.

Cause-specific baseline mortality rates are retrieved from the Global Burden of Diseases (GBD) Study 2017 (GBD Collaborative Network, 2018). This includes new datasets for projected baseline mortality rates from a recent study (Foreman *et al.*, 2018). To estimate the premature mortalities in the future, we obtained the age demographic data population projections from United Nations *World Population Prospects*: The 2019 Revision (United Nations, 2019).

Three calculation scenarios were examined for different parameters including population-weighted ozone exposure concentration and disease specific baseline mortality rates. For scenario 1 (Aging-only), the baseline values were used except the population was replaced by the projected population in year 2030. For scenario 2 (Low-exposure & Low-mortality), we estimated a decadal decrease for population weighted average (PWA) ozone exposure of 3 ppb based on a study summarizing decadal trend of PWA ozone exposure decrease in U.S. from 1990 to 2010 (Zhang *et al.*, 2018). Additionally, a 2% annual decrease in respiratory baseline mortality and a 1.5% annual decrease annual decrease in cardiovascular baseline mortality were utilized based on the baseline mortality data trend in China from the GBD project 2017. For scenario 3 (USA-baseline), we utilized a decadal decrease of population weighted ozone exposure of 6 ppb, a 3% annual decrease in respiratory baseline mortality and a 2.5% annual decrease in cardiovascular baseline mortality so that by year 2030, China will have similar population weighted ozone exposure and baseline mortality rates compared to the U.S.

Results

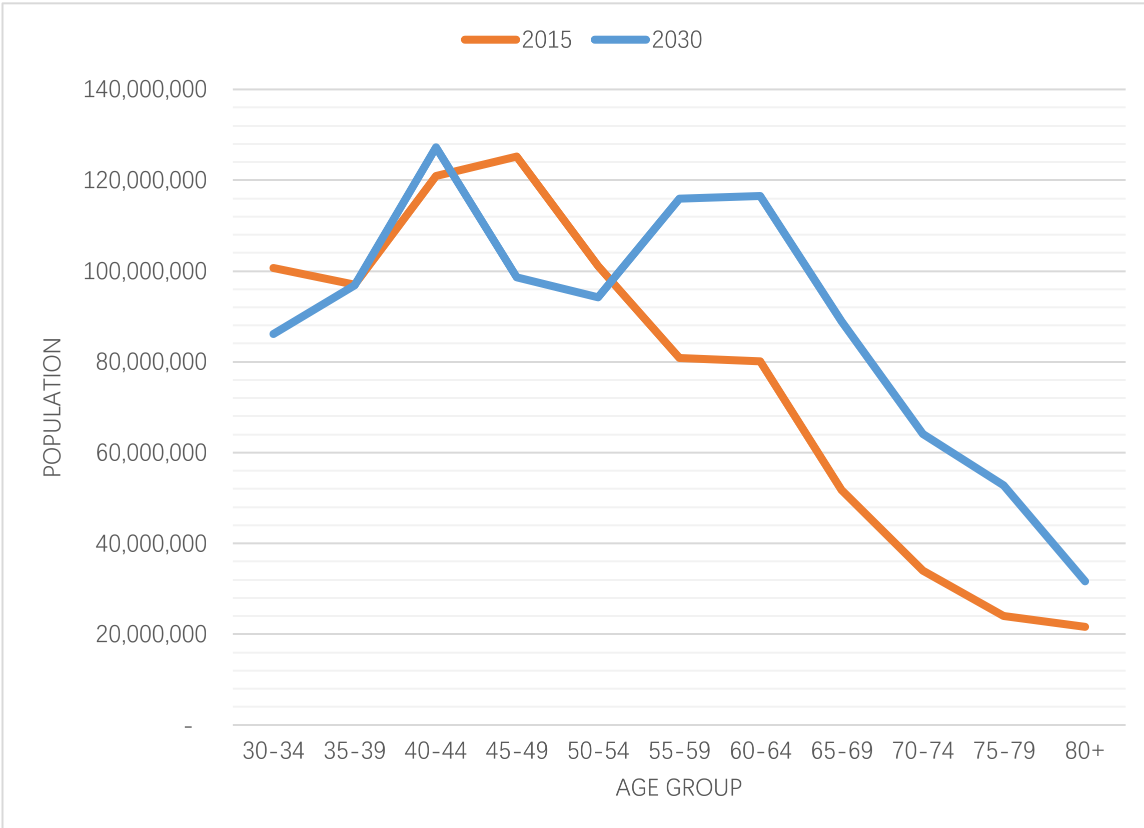

Figure 2 - China's Demographic Structure, 2015 and 2030. United Nations

The age demographic distributions for the base line year and projected year in 2030 are shown in figure 2. The population age structure in China continues to age. In year 2015, the population included 15.68% of people who are 65 years older; in year 2030, this number increased to 24.4%.

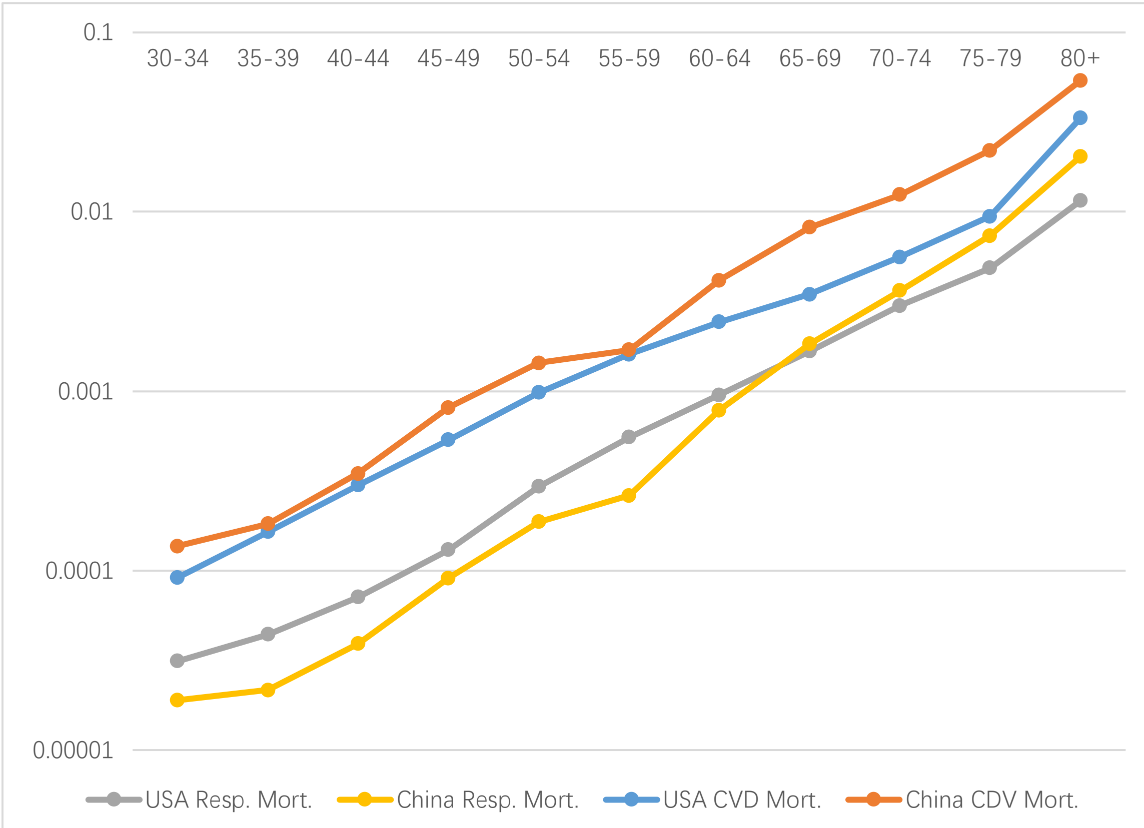

Figure 3 - Respiratory and Cardiovascular Mortality Rate Comparison: U.S. and China, 2015, log scale. GBD 2017

Figure 3 showed the disease-specific baseline mortality rates for China and the US in 2015. Overall, cardiovascular disease has higher mortality rates compare to respiratory disease. China has higher cardiovascular disease mortality rates compare to the US for all age groups. However, for respiratory mortality rates, the US has higher respiratory baseline mortality rates until the 65-year-old age bin is reached. The discrepancy starts to rise after the 65-69 age group. For 80+ age group, China has a respiratory baseline mortality rate as 0.02033 (20 death in 1000 people due to respiratory disease) while the rate in US is only 0.0115 (11 death in 1000 people due to respiratory disease).

		Baseline Case	1: Ageing Only	2: Low-exposure & Low-mortality	3: USA-baseline
Respiratory Health Impact	Mean	182	301	172	103
	Low	127	211	120	71
	High	231	382	221	133
Cardiovascular Health Impact	Mean	178	286	174	102
	Low	61	98	59	34
	High	288	465	284	167

Table 2 - Health Impact Estimations for four scenarios (reported in thousands). All results were rounded to the nearest thousand.

The results of disease specific health impacts for 4 different scenarios are listed in table 2. The respiratory and cardiovascular health impacts in the baseline scenario reported 182 000 (95% CI: 127, 231 thousand) and 178 000 (95% CI: 61, 288 thousand), respectively. Although the calculated attributable factor for cardiovascular diseases is much smaller compare to respiratory disease (0.19 for respiratory diseases and 0.05 for cardiovascular diseases), due to the higher baseline mortality rates, we obtained similar health impact numbers for the two disease specific mortalities. Compare to a previous study which reported 200 000 respiratory mortalities and 129 000 cardiovascular mortalities, the differences mainly stem from newer GBD baseline mortality rates and newer population data from UN, and to a lesser degree the population-weighted calculations versus the actual gridded calculations (Seltzer *et al.*, 2018).

Scenario 1 (Aging-only) reported 301 000 (95% CI: 211, 382 thousand) respiratory mortalities and 286 000 (95% CI: 98, 465 thousand) cardiovascular mortalities. With the overall population continues to grow and a large portion of the population getting older, China will face an almost doubled health burden from long-term ozone exposure in 2030 if there is no improvement made for the current baseline mortality rates and ozone exposure. Scenario 2 (Low-exposure & Low-mortality) reported 172 000 (95% CI: 120, 221 thousand) respiratory mortalities and 174 000 (95% CI: 59, 284 thousand) cardiovascular mortalities which are close to the mortality numbers reported in the baseline case due to continued improvements of baseline mortality rates and population-weighted ozone exposure concentration. Scenario 3 (USA-baseline) utilized PWA ozone exposure concentration and baseline mortality rates that are close to the current U.S. data, which generated a result of 103 000 (95% CI: 71, 133 thousand) respiratory mortalities and 102 000 (95% CI: 34, 167 thousand) cardiovascular mortalities in year 2030.

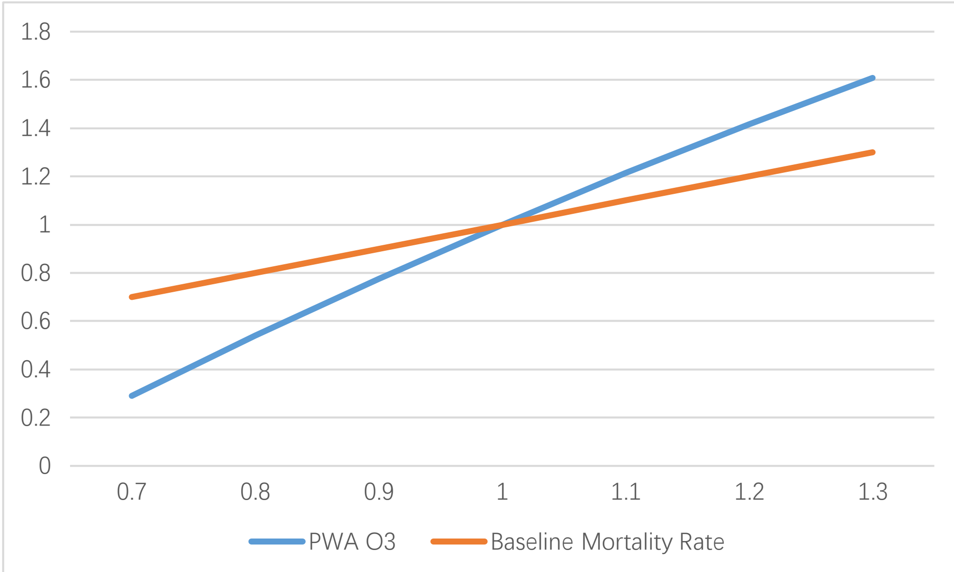

Figure 4 - Sensitivity Analysis: Population Weighted Average Ozone Concentration & Baseline Morality Rate (Axes represent multipliers).

A sensitivity analysis was carried out for population-weighted average ozone exposure level and baseline mortality rate (Figure 4). Ozone exposure has a stronger response to the multiplier compare to the baseline mortality, showing potentially higher health benefit in reducing the population weighted ozone concentration than in improving overall respiratory and cardiovascular survival rates.

Discussion & Conclusion

Trends in disease-specific mortalities due to long-term ozone exposure were projected based on pollution exposure, age demographics, and changing baseline mortality rates in China. Consistent with previous studies, the projected mortalities in 2030 will be a huge health burden to China due to population aging (Seltzer *et al.*, 2018; Cohen *et al.*, 2017). According to a recent study, capricious and arbitrary policy can greatly impact life expectancy due to air pollution exposure (Chen *et al.*, 2013). An aging population along with increasing health burden might end the demographic dividend period (a period when more resources can be used in economic investment and infrastructure development due to the rapid growth of labor force) in developing countries much quicker than previously predicted. This study has significant values to policy makers from not only developing countries that are facing pressure from population aging, but also developed countries which already have an aged population. Several policy suggestions are listed as follow.

First, reducing population-weighted ozone exposure is potentially more effective in reducing the overall health burden rather than improving overall respiratory and cardiovascular survival rates based on the different scenarios that were simulated. Thus, countries facing ozone pollution problems need to pay attention to the emission control policies as some studies have indicated inappropriate NOx and VOCs reduction policies might lead to increase in ground ozone concentration (Liu *et al.*, 2013). As the global temperature continues to increase, the frequency and intensity of extreme heat waves will also increase, leading to an increase in the incidence and prevalence of heat-related adverse health effects. Climate change is likely to increase the difficulty of controlling air pollution or undermine the effectiveness of control measures (Zhang and Wang, 2016).

Secondly, the fertility rate in China has fallen below the replacement level for years, and the mortality rate of the population decreasing to a level that are also close to those of developed countries. With the acceleration of China's economic development, especially the improvement of medical and health conditions, coupled with the continued implementation of birth planning policies, the size and increasing rate of the elderly population in China will continue to increase rapidly. Moreover, previous studies have indicated that despite vehicle emission standards getting more stricter in metropolis, due to the massive number of on-road vehicles, NOx reduction is still among the toughest tasks for environmental protection agencies. One of the policies that might reduce population-weighted ozone exposure is to accelerate urbanization. Currently, due to the imbalanced allocation of resources between urban and rural areas, people tend to move to urban cores for better healthcare and education resources. Hence, pollutants emitted by a large number of vehicles are concentrated in one specific area, making vehicle-induced emissions in urban areas hard to control. Improving quality of life outside the most populous urban centers (for instance, urbanization of second-tier or third-tier cities) could decrease density in the most populous urban cores. The population in metropolis areas can be diverted to areas with lesser ozone concentration where they will still be able to access the services they can get from urban cores (Wu *et al.*, 2011).

Thirdly, a continued public investment is still needed in the medical care systems in China, as well as the public education and awareness of air pollutants, in order to reduce the baseline mortality rates. One of the hypotheses as to why the respiratory baseline mortality rate in China after 65+ age groups are much higher is because of insufficient health care received and poor education in the harmfulness of air pollutants (Zhong *et al.*, 2007).

Future improvements can be made to this project. First, the health burden can also include more disease-specific mortalities other than the respiratory and cardiovascular diseases as studies are reporting more and more diseases related to long-term ozone exposure. Second, in additional to mortality rates, Disability-adjusted life year (DALYs) can also be added to the health burden. Thirdly, other indicators such as life expectancy or Health-adjusted life years (HALYs) might better represents impacts of policy since the effects of changing age demographics are normalized compare to total premature mortalities.

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