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Air pollution and health: A provincial level analysis of China

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Abstract

During the past 30 years, China has experienced high growth, and its economic expansion has been one of the strongest in world history. The rapid economic growth has accompanied by rapid increases in energy consumption, which has led to considerable air pollution and significantly affected mortality rate. In this study, Grossman Health Function was applied together with satellite-retrieved PM2.5 pollution data to estimate mortality rate caused by PM2.5 from 2001 to 2012. The results show some new evidence of the impact of sociological, economic and environmental factors on mortality rate of the population of China using the fixed effect (FE) and system generalized method of moments (GMM-sys) estimation methods. The PM2.5 has long-term positive significant effects on mortality. China is now experiencing a substantial mortality burden associated with current air pollution. Health care system and people's education level are important in lowering mortality.

Key words: PM2.5, Mortality rate, Temperature

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1 Introduction

Over the past several decades, China has experienced a fast pace of economic growth, with an average annual growth rate of 10%. Such an economic expansion was largely driven by energy consumption. China's total energy consumption has increased from 15.55 million tons of standard coal equivalent (tce) in 2001 to 40.21 million tons in 2012, with an average annual growth rate of 7.9%. China is now one of largest energy consumption countries and its energy consumption is expected to surpass United States by 68% in 2035. The growing energy consumption inevitably leads to the increase of air pollution (Kan *et al*., 2012). Coal, as the main fossil fuels in China's fast economic growth, constitutes about 75% of all energy generated and leads to a dramatic increase in emissions of ambient pollutants. World Bank and State Environmental Protection Agency (SEPA) (2007) estimated that air pollution has caused more than 400,000 premature deaths per year in China. Statistics from China showed that the expenditure on health per capita has increased from 393.80 yuan in 2001 to 2076.67 yuan in 2012, with an average annual growth rate of 16.32%. The rapid increase of health expenditure can be explained by the increase in demand for better health (Zhao and Hou, 2005). Extensive studies have examined the link between air pollution and the health status of the population. However, most of the economic studies about air pollution and the health status of the population have often been criticized because they did not control directly for environmental variables or other covariates, such as geographical characteristics, weather conditions, etc. Applying the Grossman health model approach, this study examines mortality as the 'output' of the health care system, and income inequality, GDP capita, population density, physicians per 1000 persons, average education level, age structure factors and temperature as 'inputs'. Econometric analyses using a fixed effects model and GMM-sys are conducted on a panel data set for 29 provinces (regions) of China over the period 2001–2012.

This paper makes two important contributions to the literature:

Firstly, this chapter studies the effect of PM2.5, urbanization, and health care on mortality rate from the empirical economic perspective. Numerous researches have investigated the air pollution on people's health from medical and epidemiology field; very few studies use the FE and sys-GMM methods to discuss this issue.

Secondly, provincial-level study is applied in this chapter. To the best of my knowledge, most studies related to the air pollution and people's health mainly used the time series data set; in this paper, we use cross-country panel data, so the results are much more persuasive. The rest of the paper is organized as follows. Section 2 briefly reviews the existing literature. In Section 3, we focus on the econometric models and data description. Section 4 provides a detailed discussion of the results of our econometric analysis, followed by conclusion in Section 5.

2 Literature review

PM2.5 is a kind of particulate matter with aerodynamic diameter less than or equal to 2.5 mm, which mainly comes from various sources that include power plants, motor vehicles, airplanes, residential wood burning, forest fires, agricultural burning, volcanic eruptions and dust storms and is formed from either the condensation of volatilized materials into primary particulate matter or from precursor gases reacting in the atmosphere to form secondary particles (Suh *et al*., 2000).

The effect of PM2.5 on health has been widely explored both in epidemiological and economic study fields.

In the epidemiological field, scientists have revealed a significant correlation between fine particle pollutants and respiratory morbidity and mortality (Pope *et al*., 1999; U.S. Environmental Protection Agency, 1996). Exposure to air pollution can increase the risk of mortality and morbidity from respiratory and cardiovascular diseases (Dockery *et al*., 1993; Pope III *et al*., 2002; Pope III, 2007; Sram *et al*., 2013). Chang *et al*. (2003) found a significant positive association between air pollution and daily mortality in Beijing. Wong *et al*. (2008) and Kan *et al*. (2007a) found positive relationship between outdoor air pollution and daily mortality in 2001–2004 in Shanghai. Venners *et al*. (2003) found the associations between daily mortality and PM2.5 were negative and statistically insignificant, which might be caused by the incomplete dataset of PM2.5. Kan *et al*. (2007a) examined the acute effects of

PM2.5 and PM10-2.5 on daily mortality in Shanghai, from March 4, 2004, to December 31, 2005, using the generalized additive model (GAM) with penalized splines to analyze mortality, air pollution and covariate data. Kan *et al*. (2007b) used a semi-parametric generalized additive model to examine the association between diurnal temperature range (DTR) and mortality outcomes from 2001 to 2004 and found a strong association between DTR and daily mortality after controlling for covariates including time trend, day of the week (DOW), temperature, humidity, and outdoor air pollution. Pope III *et al*. (2002) and Pelucchi *et al*. (2009) found that long-term exposure to particulate matter (PM) was positively associated with death from lung cancer, cardiovascular and respiratory diseases, while acute exposure to PM2.5 was linked particularly to various cardiovascular events including hospital admissions due to myocardial infarction and heart failure (Mills *et al*., 2009), as well as cardiorespiratory and all-cause mortality (Ren and Tong, 2008). Other scholars such as Anderson *et al*. (1996), Burnett *et al*. (1997), Linn *et al*. (2000) and Moolgavkar *et al*. (1997) also found the relation between the daily changes in PM air pollution and increased cardiorespiratory hospital admissions. Hoek *et al*. (2001) found death due to heart failure, arrhythmia, cerebrovascular causes and thrombolytic causes were more strongly associated with air pollution than cardiovascular deaths in general in a time series study.

Mar *et al*. (2000) claimed that total mortality was significantly associated with CO and NO (2) ($p < 0.05$) and weakly associated with SO_2, PM10, and PM(CF) ($p < 0.10$). Cardiovascular mortality was significantly associated with CO, NO_2, SO_2, PM2.5, PM10, PM(CF) ($p < 0.05$), and elemental carbon. Rossi *et al*. (1999) used a robust Poisson regression in a generalized additive model to investigate the association between air pollution and daily mortality. They found a significant association on the concurrent day, both for respiratory infection deaths and for heart-failure deaths. Cao *et al*. (2011) found significant associations between air pollution levels and mortality from cardiopulmonary diseases and from lung cancer and examined the association of air pollution using proportional hazards regression model in 70,947 middle-aged men and women of the China National Hypertension Survey.

Matus *et al*. (2011) evaluated air pollution-related health impacts on the Chinese economy using an expanded version of the emission prediction and policy analysis model and concluded that air pollution had caused substantial socioeconomic burden to China's economy. In Europe, the APHEA (air pollution and Health: a European Approach), and North America, the NMMAPS (National Morbidity, Mortality and Air Pollution) using the multi-site time-series approach found the similar effects of air pollution on economic growth.

In the field of health economics, the seminal demand-for-health model is a corner-stone in analyzing the health and air pollution. Grossman (1972a, b) was the first economist to present a formal model on the determinants of health drawing on the theory of human capital by Becker (1965). In the Grossman model, it is assumed that individuals inherit an initial stock of health that depreciates with age and can be increased by investment. The optimal amount of investment should be where the marginal cost of health production equals the marginal benefits of improved health status. The health status was assumed to affect utility both indirectly through raising labor income and directly by assuming that individuals value good health per se (Gerdtham *et al*., 1997). By applying the Grossman health function, much empirical work has been carried out to estimate the relationship between health and air pollution (Cropper, 1981; Gerking *et al*., 1986; Pohlmeier *et al*., 1995; Rosenzweig and Schultz, 1982; Harrington and Portney, 1987; Alberini *et al*.,1997). Gerking *et al*. (1986) estimated the marginal willingness to pay for the "average" employed person in St. Louis to enjoy a 30% reduction in outdoor ozone exposures. Cropper (1981) considered the health depreciation effect of air pollution and estimated the willingness of people to pay for a change in air quality. The results implied that the average person in the 1976 sample, who earned $6.00 per hour, would pay $7.20 annually for a 10 percent decrease in the mean of SO_2. Alberini *et al*. (1997) studied the willingness of individuals pay for health improvements associated with air pollution in Taiwan and found that the willingness of people to pay to avoid illness increased with duration of illness, with the number of symptoms experienced, and with education and income. Similar work has also been done by Harrington and Portney (1987) and Berger *et al*. (1987). Dustmann and Windmeijer (2000) found evidence of negative transitory, and positive permanent effects by estimating dynamic health and health input demand equations using panel data set in the framework of a life cycle model. Dardanoni and Wagstaff (1990), Picone *et al*. (1998), Liljas (1998) explored the implications of uncertainty for the optimal demand for health. Blakely *et al*. (2002), Kennedy *et al*. (1998), Lopez (2004), Soobader and LeClere (1999) and Subramanian and Kennedy

(2001) examined the effect of income inequality on health at different geographical levels such as states, metropolitan areas or countries. These results suggested that the level of geographic aggregation influences the pathways through which income inequality is actualized into an individuals' morbidity risk and individual-level factors (such as low income, being black, smoking) are strongly associated with self-rated poor health. Wilkinson and Pickett (2006) found that the studies of income inequality in large areas are more supportive of the association between inequality and health compared to those in small areas through reviewing the 155 papers related to income inequality and population health. Subramanian and Kawachi (2006) found higher state-level income inequality has been linked to higher all-cause mortality risk. However, this effect of income inequality might become insignificant when the income level of rural areas reaches some threshold level that can provide rural people with higher living standards with the economic growth even though the gap between rural and urban areas is expanding. The income effect of reducing mortality rates is limited and may well lead to the sort of stressful and unhealthy lifestyle that could adversely affect the health status of the population (Fuchs, 1994; Auster *et al*., 1969). Zhang *et al*. (2017) claimed that the premature mortality not just related to local sources of air pollution but also be affected by atmospheric transport of pollution from distant sources. They estimated premature mortality caused by PM2.5 in different world regions using the four global models. Their results showed that of the 3.45 million premature deaths related to PM2.5 pollution in 2007 worldwide, about 12% (411,100 deaths) were related to air pollutants emitted in a region of the world other than that in which the death occurred, and about 22% (762,400 deaths) were associated with goods and services produced in one region for consumption in another. Healy (2002) stated that strong, positive relation with environmental temperature and strong negative relation with thermal efficiency indicate that housing standards in southern and western Europe play strong parts in such seasonality by observing the association between temperature and mortality across European countries. Hajat *et al*. (2014) claimed that the elderly (≥ 65 years old) were more vulnerable to temperature variation when compared with young people. Moreover, the pattern of this relationship may differ for areas with different weather patterns, latitudes, air pollution levels and prevalence of air-conditioning systems. Tam *et al*. (2010) reported significant associations between diurnal temperature range and cardiovascular mortality among the elderly in Hong Kong using a generalized additive model. Yan *et al*. (2009) also found a significant positive correlation between diurnal temperature range and chronic obstructive pulmonary disease visits in Taiwan.

Based on the previous economic and epidemiological studies, aside from the factors associated with biological and genetic considerations that have been linked with reduced health status, the factors that might influence population health can be grouped into two categories: socioeconomic factors and environmental factors.

3 Methodology and model specification

3.1 Model specification

Based on the health production function (Grossman, 1972a, 1972b; Cropper, 1981; Gerking *et al*., 1986; Alberini *et al*., 1997; Zhao and Hou, 2005), we use static and dynamic panel data models to analyze the impacts of air pollution on mortality rate; the models are represented as follows:

$$lnmortality_{it} = a_1 lnPM_{it} + a_2 lninequality_{it} + a_3 lntemperature_{it} + X'_{it}\beta + \eta_i + \delta_t + e_{it} \quad (1)$$

$$lnmortality_{it} = \gamma l.lnmortality_{it-1} + a_1 lnPM_{it} + a_2 lninequality_{it} + a_3 lntemperature_{it} + X'_{it}\beta + \eta_i + \delta_t + e_{it} \quad (2)$$

Equation (1) is the static model used in the paper; Equation (2) is the dynamic model, which added one period of lagged dependent variable $lnmortality$ into Equation (1). The reasons for adding the lagged dependent variable are to capture the effects of the past economy and to rid the model of autocorrelation.

where the subscript i refers to province, $i = 1,2,3,\ldots,29$; and t is time year; δ_t is the variable that is used to capture the other factors that are changed with the time, such as the environmental regulation, price of energy, the progress of technology etc. η_i is to measure the difference among each province. e_{it} is the error term. $mortality_{it}$ is the main explanatory variable of this paper as a measure of health status of the population, which measured in units of deaths per 1,000 individuals per year in each province in time t. PM_{it} is PM2.5 emission intensity ($ug\ per\ cubic$) of each province i in time t. $inequality_{it}$ refers to the income disparity between urban residents and rural residents, which is calculated by the disposable income of urban residents to the rural residents.; $temperature_{it}$ refers to annual average temperature level of province i in time t;e_{it} is the error term, and a is the constant.

$X_{1it}^{'}$ are the other control variables, which include the old dependency ratio, the physicians per 1,000 persons; the population density and the average education level of each province.

The old age dependency ratio is measured as the population of aged 65 or above to the total population. Population density is the measure of the number of people per square kilometer. The years of schooling is the average education year of the population aged 6 and over. [3] The physicians per 1,000 persons is a straightforward measurement of the ratio of physicians per head of population. The description of the main variables is given in 3.3.3 section.

3.2 Data source

The data used in this paper mainly were obtained from each year's China Statistical Yearbooks (2002–2013), Yearbooks of Health of China (2002–2013), China Industrial Yearbooks (2002-2013), provincial statistical yearbooks of each province (2002–2013) and the meteorological administration of each province. The PM2.5 data (2001–2012) were obtained from Battelle Memorial Institute and Center for International Earth Science Information Network at Columbia University. The dataset is a balanced panel that consists of observation for 29 provinces[4] covering the period 2001–2012. The 29 provinces are

[3] China's education system can be classified four categories: primary, secondary, high and college and above education. The primary education is 6 years; secondary education is 9 years; high education is 12 years and college and above is 16 years. The function can be written as follow:

Average education year= percent of population of primary education*6+seconary*9+high*12+college and above*16

[4] Hong Kong, Macao and Tibet are not included due to lack of available data are not available or lost. The information about Chongqing and Sichuan provinces is merged together.

shown in Table 1. The definition of the variables is shown in Table 2. Table 3 displays the descriptive statistics of the variables employed for the empirical estimation.

Table 1 Distribution of the 29 administrative regions

Area	Administrative regions
Northeastern	Heilongjiang, Jilin, Liaoning
Northern	Neimenggu, Beijing, Tianjin, Hebei, Shandong, Henan, Shanxi, Shaanxi
Southern	Jiangsu, Zhejiang, Fujian, Guangdong, Hubei, Hunan, Hainan, Shanghai, Anhui, Jiangxi
Western	Qinghai, Xinjiang, Ningxia, Gansu
Southwestern	Yunnan, Guizhou, Guangxi, Sichuan

Table 2 Definition of all the variables

Variable	Definition	Units of measurement
Mortality	The units of deaths per 1,000 individuals per year	‰
PM2.5	PM2.5 emissions intensity	ug per m^3
Physician	Physicians per 1000 Persons	person
Inequality	The ratio of disposable income of urban to that of rural	%
Old age dependency ratio	Old dependency ratio (aged 65 years old and over)	%
Years of schooling	The average number of years of education	year
Population Density	The number of people per square kilometer	person/km^2
Temperature	Annual average temperature level	℃

Table 3 The statistical description of the data in the model

Variable	Obs	Mean	Std. Dev.	Min	Max
Mortality	348	5.95	0.65	4.21	7.57
PM2.5	348	27.09	11.60	2.17	7.95
Physician	348	4.28	1.65	1.96	14.20
Inequality	348	3.01	0.596	1.949	4.759
Old	319	0.087	0.018	0.048	0.164
Years of schooling	348	8.28	0.97	6.04	11.84
Density	348	431.90	586.31	7.27	3754.62
Temperature	348	14.09	5.324	2.9	25.4

3.3 Main explanatory variables specification

Health status

$mortality_{it}$ is the main explanatory variable of this paper as a measure of health status of the population, which represents the units of deaths per 1,000 individuals per year of each province in time t.

Air pollution

PM_{it} is PM2.5 emission intensity ($ug\ per\ cubic$) of each province i in time t. Here the paper uses PM2.5 as an indicator to measure air pollution, as the study from Health Effect Institute (HEI) (2012) estimated that the premature death of China in 2010 had reached up to 120 which was mainly contributed by PM2.5. Portney and Mullahy (1990) claimed that PM2.5 is an effective and exact indictor for measuring the air pollution, which showed significant effects on health.

Income inequality

$Income\ inequality_{it}$ refers to the income disparity between urban residents and rural residents, which is calculated by the ratio of average disposable income of urban residents to that of rural residents. Higher income usually comes with higher living standards: better health care, abundant nutrition etc. However, this effect of income inequality might become insignificant when the income level of rural areas reaches some threshold level that can access higher living standards with economic growth even though the gap between rural and urban areas is expanding.

Annual average temperature level

China has a great diversity of climates because of tremendous differences in latitude, and altitude. The northeast experiences hot and dry summers and bitterly cold harsh winters, with temperatures known to reach as low as $-20^{\circ}c$. The north and central region has almost continual rainfall, temperature in summers reaching $26^{\circ}c$ and cool winters when temperatures reach $0^{\circ}c$. The southeast region has substantial rainfall, and can be humid, with semi-tropical summer. Temperature has been known to reach over $40^{\circ}c$, although this is highly unusual, but during summer temperature over $30^{\circ}c$ is normal. Winters are mild, with lows of around $10^{\circ}c$ in January and February. He *et al*. (2001) found the seasonal variation of PM2.5 concentration was remarkable, with the highest in winter and the lowest in summer by collected PM2.5 concentration data from July 1997 to September 2000 in the city center and urban area in Beijing.

Here $temperature_{it}$ refers to the average annual temperature level of province i in time t. The temperature can affect mortality rate by two ways. Firstly, the low temperature can cause the physical discomfort, especially to the old people; secondly, the low temperature can lead to the increase of the energy consumption and then cause the pollution emission increase then affect the mortality. The level of PM2.5 usually rises during the winter when demand for heating soars and coal-fired power plants are used more intensively.

Old age dependency ratio

The old age dependency ratio is measured as the population of aged 65 or above to the total population. According to the United Nations, China is aging more rapidly than almost any country in recent history. China's dependency ratio will reach up to 44% by 2050. Old people as a vulnerable group are more likely to succumb to a disease.

Population density

Population density is measured by the number of people per square kilometer, which is a proxy for a collection of potential positive and negative health related factors, such as congestion, pollution, shortage of resources, and access to health care. Therefore, the net effect of population density on mortality is mixed.

Years of schooling

Years of schooling is the average number of years of education for the population aged 6 and over. The average years of education can fully reflect the average education level of the population. It has proved more educated populations are expected to have lower death rates (Thornton, 2002). Education is thought to be beneficial to the wellbeing of the population as individuals can increase their health knowledge and improve their ability to process health information (Grossman, 1972; Montez and Zajacova, 2013; Hummer and Lariscy, 2011; Mirowsky and Ross, 2003).

Physicians per 1000 persons

The physicians per 1000 persons is another key factor related to health. Previous literature has proved the increase of physicians provides people with better access to health care, which can reduce the waiting times and help to prevent illness and death (Starfield *et al*., 2005). People who receive care from primary care physicians are healthier. Studies in the early 1990s (Shi, 1992, 1994) showed that those U.S. states with higher ratios of primary care physicians to population had better health outcomes. Vogel and Ackerman (1998) subsequently showed that the supply of primary care physicians was associated with an increase in life span and with reduced low birth-weight rates. Shi *et al*. (2003) found the effect of supply of primary care physicians was significantly associated with reduced mortality and even wiped out the adverse effect of income inequality.

4 Empirical results and analysis

4.1 Unit root test

To investigate the possibility of panel cointegration, we employ LLC, ADF-fisher and IPS tests to determine the existence of the unit roots in the data series. The results demonstrate that the minority of the variables are non-stationary (Table 4), but their first difference series are stationary (Table 5).

Table 4 Results of panel unit root tests for level

Variable	Intercept			Intercept and trend		
	LLC	ADF-fisher	IPS	LLC	ADF-fisher	IPS
Mortality	-5.100***	105.459***	-3.777***	-8.269***	110.903***	-4.069***
PM2.5	-17.742***	77.685***	-2.938***	-2.988***	43.576	1.958
Physician	10.451	6.502	12.214	-4.788***	46.573	2.816
Income inequality	-7.103***	100.554***	-3.081***	-7.427***	52.975	1.072
Old age dependency ratio	-6.324***	71.279	91.838**	-10.646***	88.203***	-2.264**
Years of schooling	0.284	30.876	4.111	-9.216***	108.769***	-4.141***
Population density	-5.501***	47.174	2.535	-7.884***	71.718	-0.005
Temperature	-7.573***	105.236***	-4.421***	-10.572***	94.574***	-3.495***

Note: Lags are all automatically selected by SIC standard. *, ** and *** indicates rejection of the null hypothesis of no unit root at 10%, 5% and 1% levels of significance.

Table 5 Results of panel unit root tests for first difference

Variable	Intercept			Intercept and trend		
	LLC	ADF-fisher	IPS	LLC	ADF-fisher	IPS
Mortality	-17.664***	238.642***	-12.238**	-16.446***	180.137***	-6.632***
PM2.5	-19.105***	240.888***	-12.361***	-17.525***	163.310***	-6.310***
Physician	-10.280***	116.461***	-4.707***	-15.668***	136.749***	-4.810***
Income inequality	-12.380***	141.116***	-6.721***	-18.363***	182.246***	-6.815***
Old age-dep ratio	-17.208***	222.880***	-11.524***	-12.887***	153.951***	-5.335***
Years of schooling	-20.373***	265.499***	-14.076***	-19.859***	201.936***	-9.334***
Population density	-8.768***	149.426***	-6.554***	-5.027***	87.363***	-1.107***
Temperature	-22.308***	284.011***	-15.009***	-20.171***	202.255***	-7.879***

Note: Lags are all automatically selected by SIC standard. *, ** and *** indicates rejection of the null hypothesis of no unit root at 10%, 5% and 1% levels of significance.

4.2 Panel cointegration tests

After the unit root test, Pedroni (1999, 2001, and 2004) test for long run cointegration is also used in this chapter. The results indicate that 4 out of 7 statistics reject the null hypothesis of non-cointegration at the 1 percent level of significance. It is shown that independent variables do hold cointegration in the long run. However, since most of the statistics conclude in favor of cointegration, and this, combined with the fact that the according to Pedroni (1999) the panel non-parametric (*t*-statistic) and parametric (*adf*-statistic) statistics are more reliable in constant plus time trend, lead us to conclude that there is long run cointegration among our variables in the panel data sets.

Table 6 Results of Pedroni panel cointegration test

Test	Intercept	Intercept+ Trend
Panel *v*-Statistic	-5.6354	-8.1841
Panel *ρ*-Statistic	6.7038	7.8014
Panel *t*-Statistic: (non-parametric)	-11.1391***	-23.0666***
Panel *t*-Statistic (*adf*): (parametric)	-4.1641***	-6.9923***
Group *ρ*–Statistic	8.7662	9.6009
Group *t*-Statistic: (non-parametric)	-21.9800***	-29.5729***
Group *t*-Statistic (*adf*): (parametric)	-5.9132***	-8.2498***

Note: All statistics are from Pedroni's procedure (1999) where the adjusted values can be compared to the N (0,1) distribution. The Pedroni (2004) statistics are one-sided tests with a critical value of -1.64 (k < -1.64 implies rejection of the null), except the v-statistic that has a critical value of 1.64 (k > 1.64 suggests rejection of the null). *, ** and *** indicates rejection of the null hypothesis of no-cointegration at 10%, 5% and 1% levels of significance.

4.3 Results and analysis

Table 7 Estimation results of static panel model

Variables	(1)	(2)	(3)	(4)	(5)
Income inequality	0.108	0.164	0.160	0.161	0.159
	(0.114)	(0.101)	(0.102)	(0.102)	(0.096)
PM2.5	0.074**	0.054*	0.052**	0.051**	0.045**
	(0.028)	(0.027)	(0.024)	(0.023)	(0.021)
Physicians	-0.125***	-0.072**	-0.062*	-0.063**	-0.059*
	(0.040)	(0.031)	(0.031)	(0.031)	(0.036)
Old age-dep. ratio		0.193***	0.196***	0.196***	0.131**
		(0.049)	(0.047)	(0.047)	(0.055)
Years of schooling			-0.378**	-0.378**	-0.413**
			(0.152)	(0.153)	(0.166)
Temperature				0.010	0.008
				(0.038)	(0.037)
Population density					-0.226
					(0.138)
Constant	1.622***	2.060***	2.833***	2.813***	3.972***
	(0.155)	(0.165)	(0.313)	(0.295)	(0.803)
Observations	348	348	348	348	348
R-squared	0.154	0.244	0.271	0.271	0.295
Number of id	29	29	29	29	29

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 8 Estimation results of dynamic panel model

Variables	(6)	(7)	(8)	(9)	(10)
L.mortality	0.573***	0.523***	0.521***	0.503***	0.525***
	(0.091)	(0.098)	(0.086)	(0.094)	(0.089)
Income inequality	-0.020	0.033	-0.002	0.004	0.028
	(0.033)	(0.034)	(0.039)	(0.040)	(0.041)
PM2.5	0.022**	0.017*	0.018*	0.018	0.011
	(0.011)	(0.010)	(0.010)	(0.017)	(0.015)
Physician	-0.077***	-0.084***	-0.045	-0.055**	-0.062**
	(0.024)	(0.022)	(0.031)	(0.026)	(0.024)
Old age-dep. ratio		0.117**	0.131***	0.153***	0.129**
		(0.045)	(0.046)	(0.058)	(0.055)
Years of schooling			-0.204*	-0.193*	-0.186**
			(0.111)	(0.096)	(0.080)
Temperature				-0.013	-0.027
				(0.019)	(0.018)
Population density					0.012**
					(0.005)
Constant	0.815***	0	0	1.715***	0
	(0.183)	(0.000)	(0.000)	(0.390)	(0.000)
AR (1)	0.000	0.000	0.000	0.000	0.000
AR (2)	0.689	0.822	0.727	0.806	0.828
Hansen	0.233	0.203	0.180	0.160	0.159
Observations	319	319	319	319	319
Number of id	29	29	29	29	29

Note: All the models are included the year dummies; Standard errors in parentheses; the prob > z for AR and Hansen test are also reported in parentheses; the predetermined variable is L.lnmortality; *** p<0.01, ** p<0.05, * p<0.1.

Tables 7 and 8 display the descriptive analysis and the bivariate relations between mortality and the influencing factors using FE and sys-GMM estimation methods by stepwise regression. The fixed effect (FE) assumption is that the individual specific effect is correlated with the independent variables. FE has the advantage in exploring the relationship between predictor and outcome variables within a country (Reyna, 2007). As known, each province of China has its own individual characteristics, which means that the FE is much more suitable for our study. The results of AR (2) show that the assumption that the models have no second autocorrelation cannot be rejected, and the instrumental variables of these models are valid through the Hansen test, which confirmed that the GMM-sys is efficient in our study. Specifically, the results revealed that the air pollution indicated by PM2.5 has a significant positive effect on mortality rate, which demonstrates that PM2.5 is one of the contributors to the health status of the population. More interestingly, the effect of PM2.5 on mortality rate decreased when we controlled the other influencing factors, such as years of schooling, the number of physicians etc. It proved that the change of public service and social environment can alleviate the effect of PM2.5 on mortality rate. Specifically, Specification 1 and 6 as the basic regression model estimated the effects of income inequality, PM2.5 and health care (represented by the number of physicians per 1000 person) on mortality rate. Based on model 1, model 2 -5 further controlled the other influencing factors: number of physicians, years of schooling, temperature and population density. The results show that the air pollution indicated by PM2.5 has a significant positive effect on the increase of mortality rate. When the years of schooling, population density and average temperature level are included, the effect of $PM_{2.5}$ on mortality rate becomes less than that of the specification 1. The reasons behind this finding may be: 1) the improvement of public health can decrease the influence of PM2.5 on people's health status; 2) the awareness of air pollution may motivate people to carry out some measures to protect themselves. In other words, the effect of air pollution on the health status of people might be a slow process. Contrary to the previous findings (Coburn, 2000; Lynch *et al*, 2000), our result shows that income inequality is not insignificant associated with mortality in all specifications. There is no apparent evidences show that the increase of income inequality can induce mortality. According to the "nonmaterialism hypothesis", income inequality may harm health status through its effect on the level and distribution of material resources. However, the rapid economic growth can alleviate this effect. We can see China's rapid economic growth is beneficial to all the people who can afford the medical care, goods and services; although the income gap between rural and urban is widening. Easterlin (1999) argued that it was commonplace in economics to believe that improvements in population health were mostly a serendipitous byproduct of economic growth. The income inequality measures the difference of relative income of rural and urban residents. However, the increase of absolute income guarantees the poor people can get the necessities. Preston (1996) proposed that more efficient public health technology is the main reason for the increase of life expectancy in poor countries during the 20th century. China is the first large nation in the world to develop a nationwide rural health insurance system in the 1970s. In 2011, it has successfully achieved universal health insurance coverage—95% of Chinese population was insured, compared with less than 50% in 2005 (Yu, 2015). The coverage is offered through three public insurance programs: New Rural Cooperative Medical Scheme (NRCMS), launched in 2003 in rural areas. Its enrollment rose to 97% of rural population in 2011 (Meng and Tang, 2013); Urban Resident Basic Medical Insurance (URBMI), launched in 2007 to target the unemployed, children, students, and the disabled in urban areas. It covered 93% of the target population in 2010 (Yip *et al*., 2012) and urban Employee Basic Medical Insurance (UEBMI), launched in 1998 as an employment-based insurance program. Its coverage reached 92% in 2010 (Yip *et al*., 2012). The universal coverage of the health insurance let many people have the chance to access to basic healthcare service. The old age dependency ratio is a contributor to the increase of mortality rate, with elasticities ranging from 0.117 to 0.196. According to China's Statistic Bureau, China had 230 million people aged 60 and over by the end of 2016 that makes it the only country in the world with an elderly population of over 200 million. In fact, China is getting older faster than anywhere else in the world. The number of Chinese older than 60 is expected to rise to more than 487 million in 2050—more than the combined populations of Germany, Japan, France and Britain—compared to just 100 million in 2005. The Chinese government has a very weak safety net to cover for them all. Apparently the rapidly increasing ageing population will principally impact the labor market and mortality rate.

The elasticities for physicians per thousand persons are significantly negative under most of the specifications, indicating that if the number of physicians per thousand persons increases by one unit, mortality rate will decrease between 0.055 to 0.125. Studies in the early 1990s (Shi, 1992, 1994) showed that those U.S. states with higher ratios of primary care physicians to population had better health outcomes. Vogel and Ackerman (1998) subsequently showed that the supply of primary care physicians was associated with an increase in life span and with reduced low birth-weight rates. Shi *et al*. (2003) found the effect of supply of primary care physicians was significantly associated with reduced mortality and even wiped out the adverse effect of income inequality. The same result also found by Starfield *et al*. (2005) that the increasing numbers of physicians provides people with better access to health care, which can reduce the waiting time to see a doctor and help to prevent illness and death.

The factor of years of schooling demonstrates that an increase in the years of schooling has a significantly negative effect on mortality rate. The more educated are more likely to live longer not just in the China (Liang *et al*. 2000), but also in US (Cutler and Muney, 2008a) and Canada (Mustard *et al*. 1997), Israel (Manor *et al*. 2001) and Russia (Shkolnikov *et al*. 1998).

Similar results also documented in developing countries, such as Bangladesh (Hurt *et al*. 2004) and Korea (Khang *et al*. 2004). Two factors that partly explain the education advantage are that people who have a higher level of education usually have a better lifestyle (educated people are less likely to smoke or engage in other risky behaviors) and have health insurance (people with more education tend to have better coverage than those with less education).

We further control the influencing factor of temperature in specifications 4, 5, 9 and 10 and find the effect of temperature on mortality are not significant. In terms of the influencing factor of population density, it does not show significant effects on mortality rate using the FE estimation method. Wang *et al*. (2013) who examined the case of Canada, France, Japan and the United States and found the death rate decreases with density before the population density reaches 300 per square kilometer among the young age-groups. According to provincial dataset, the population density of most of the regions far more than 300 per square kilometer: the population density of Shanghai city has reached 3754.62 in 2012. Using sys-GMM method, the results show that one unit increase of population density will increase mortality rate by 0.012%. The increase of population density paired with inadequate economic performance and other constraints can result in urban residents increasingly living in areas with overcrowded or deteriorating housing, few social amenities, poor environmental and sanitary conditions and a lack of economic opportunities. Such conditions are associated with an increased risk of infectious disease and death (Barrett, 2010).

4.5 Collinearity diagnostics

VIF test is used to check the multicollinearity between the variable. By applying the VIF test, the results (Table 9) show that the values of VIF are all less than 10 and the values of Tolerance are more than 0.1, which means that multicollinearity is also not a problem in this paper.

Table 9 Results of collinearity diagnostics

Variable	VIF	SQRT	Tolerance.	R^2
PM2.5	1.38	1.17	0.7258	0.2742
Physician	4.06	2.02	0.2461	0.7539
Income inequality	2.15	1.46	0.4661	0.5339
Old age dep. ratio	2.10	1.45	0.4768	0.5232
Years of schooling	5.01	2.24	0.1997	0.8003
Population density	2.97	1.72	0.3365	0.6635
Temperature	1.88	1.37	0.5312	0.4688
Mean VIF	2.79			

5 Conclusion

Using panel data of 29 provinces during 2001-2012, the paper explores the effect of driving forces of PM2.5, old age dependency ratio, physicians per thousand persons, years of schooling, population density and annual average temperature level on mortality rate using the FE and sys-GMM estimation methods. The effects of income inequality on mortality demonstrate that the negative effect of income inequality on mortality is offset by the economic growth. The economic growth has resulted in general improvements in the quality of life and increased healthcare provision with decreasing infectious disease burden and mortality (Liu *et al*., 2008). It implies that promoting the economic growth should be still the priority in China's development, even though the income gap is widening. Meanwhile, the government should give more policy and finance support to rural areas and give priority to efficiency with due consideration to fairness.

The increase of mortality is associated with an increase in PM2.5 emission. China should establish relevant environment guidelines and gradually build up monitoring systems across the country. On one hand, government should take measures to reduce coal consumption and encourage research and application of clean coal combustion technology to improve the energy efficiency. This can be done by adjusting the industrial structure, encouraging the development of high-technology. On the other hand, the massive scale of PM2.5 and its cross-border impact means that regional cooperation is necessary, the developed province mainly located in the eastern part should offer its knowledge and experience gained while battling its own severe air pollution problems in the past to help the developing provinces. A regional PM2.5 monitoring network should be built and be served as a model for such cooperation. Furthermore, it is necessary to optimize international trade structure. Some policies should be implemented to support the high-tech exports products and limit the high energy-consumption export products. Meanwhile, China should reduce PM2.5 emissions from transport sector and expand the new energy (electricity and bio-energy) automobile consumption (Xu *et al*., 2016). The government should strengthen the research and application of electric vehicle technology and provide subsidies for the purchase and use of new energy vehicles.

Increasing the years of schooling is one of the measures that contribute to the decrease in mortality rate. The increase in education years can promote people to adopt a healthy lifestyle and encourage easy access to health care. According to the Population Sampling Survey conducted by National Bureau of Statistics in 2005, the number of years of schooling of the country's labor force was 8.6 years on average (the rural areas were 8 years; the urban areas were 12 years), while only 25% of the labor force (aged between 15 and 65) had an education level of junior high school or above. Comparing with the other developing and developed countries experiencing economic transition, the lack of human capital accumulation and the substantial education inequality was widely observed between rural and urban areas. The government should increase public investment in education and provide necessary skill training for the labor force, especially in the rural areas.

From the perspective of health care service, increasing the number of physicians is a necessary way for people to gain easier and better access to the health service. It implies that the government and society should improve physicians' social status and improve their material treatment to attract more people to the medical profession. Meanwhile, the government should encourage the private investment on public healthcare and establish an advanced social healthcare system.

With the rapid urbanization, many people will migrate from rural areas to urban areas in next few decades. Overurbanization could be a problem for China's sustainable development. The rapid increase of population density will impact on infrastructure, environmental health and human wellbeing. Implementing appropriate policies to protect the environmental health of this expanding demographic both at the individual and the community level is important. China's urbanization program is an important part of structural reform, as the nation transitions to a more productive, service-based economy. The government should take measures to encourage rural migrants to settle in smaller towns and cities rather than larger cities due to overpopulation in larger cities. Local governments are also required to improve the construction of cities' infrastructures.

The increase of old age dependency ratio contributes to mortality rate, which occurs against a backdrop of a declining birth rate. As the strict family planning policy implemented over the several decades (1979–2015), the fertility rate in China continued its fall from 2.8 births per woman in 1979 (already a sharp reduction from more than five births per woman in the early 1970s) to 1.5 in 2010 (Wang *et al*., 2012). The dramatic fertility declines and improves longevity over the past two decades are causing China's population to age at one of the fastest rates ever recorded, accompanied by an increase in the prevalence of chronic disease and disability in the population. According to the United Nations, China is ageing more rapidly than almost any country in recent history. China's dependency ratio for retirees could rise as high as 44% by 2050. With the growing elderly population, meeting the health and long-care will result in soaring health care costs. The above results have important implications. Firstly, setting up long-term care delivery systems for the elderly and building up the various chronic-disease prevention program is urgent and necessary at the national and provincial level. The government should provide preferential policy for the private sectors or personal to invest on the elder homes, which can work together with government-sponsored elder homes and familial elder care systems.

Both informal and local government-supported long-term care services for the elderly in China can be based in the community, which can provide elderly and their family with daily care, information, home maintenance and referral services.

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