The impact of public participation in environmental behavior on haze pollution and public health in China

ABSTRACT

This study extends the STIRPAT model based on Grossman's health production function and uses Chinese provincial panel data from 2000 to 2017 to examine regional differences in the impacts of public participation in environmental behavior (PPEB), other socioeconomic factors related to haze pollution, and public health level (PHL) in China. We use four econometric techniques and obtain robust results. Overall, results from the system-GMM indicate that an inverted U-shaped relationship, which has not passed its inflection point, exists between PPEB and haze pollution, PPEB and PHL in the different regions, urbanization, and haze pollution except in the eastern region. Both fossil energy consumption and population density promote haze pollution. Income per capita contributes to haze pollution only in the country as a whole and the western region, but improves PHL in the whole of China and the three regions. There is a negative correlation between haze pollution and PHL in each sample. Medical services are substantially conducive to PHL, except in the western region.

JEL classification: Q57 I18 R15

Key words: Public participation in environmental behavior; Public health level; Haze pollution; Inverted "U" shape

Highlights

- An inverted U-shaped relationship exists between public participation in environmental behavior and haze pollution.
- Urbanization and haze pollution have an inverted U-shaped relationship, except in the east.
- Haze pollution could lower China's PHL in the eastern, central, and western regions.
- Both fossil energy consumption and population density promote haze pollution.
- We employ four econometric techniques from panel estimations to obtain robust results.

*Corresponding author： qugh@sxufe.edu.cn （G.Qu）
**Corresponding author: quweihua@sxu.edu.cn （W.Qu）

1. Introduction

Health is the collective effect of social, economic, and physical conditions (Jiang et al., 2020; Keček et al., 2019; Peres et al., 2019), and thus a country's public health level is an important dimension and sensitive tracer of sustainable development. China has undergone rapid economic development since implementation of the "Reform and Opening-up" policy in 1978, and this economic development mainly depends on energy consumption, especially fossil fuels. Fossil energy is a determinant for sustainable development of the economy because of the imbalance in China's energy consumption structure (Dong, Yu, et al., 2019; Wei & Zhang, 2020). Many air pollutants, such as sulfur dioxide (SO_2), dust, soot, and total suspended particles (TSP) are injected into the atmosphere during fossil fuel burning and transformation processing (Oreggioni et al., 2019). These pollutants—and especially haze pollution, which mainly consists of particulate matter with a diameter of less than 2.5 micrometers ($PM_{2.5}$)—not only damage air quality but are also harmful to public health. How to alleviate the amount of haze pollution and improve the public health level (PHL) is a major concern for both policymakers and academia. Previous research on haze pollution and PHL suggests that public participation in environmental behavior (PPEB), environmental regulation, urbanization, and enterprise environmental behavior are important enforcing factors for serious haze pollution and PHL. Therefore, PPEB can protect the public from serious haze pollution by consuming more green energy than fossil energy, supporting government regulation, and limiting the pollutant emissions of enterprises. These actions, in turn will reduce death rates.

In recent years, with the increase in living standards, PPEB activity is increasingly more common and popular. PPEB, supported by public participation in environmental protection, is gradually becoming an essential part of China's environmental governance. This is because it can help mitigate information asymmetry between governments and enterprises, support strict government supervision and green transformation for enterprises, and, even more important, advocate for low-carbon practices. These actions, in turn, decrease pollutant emissions and improve PHL. According to a report released by the Policy Research Center for Environment and Economy of China's Ministry of Ecological Environment, the scale of PPEB has improved and more respondents believe that paying attention to information on the ecological environment and practicing green consumption is important for protecting the environment. Notably, the proportion of the population concerned with environmental governance increased by 10% in 2010 to 20% in 2016. It appears that the battle against haze pollution has achieved positive results, and ecological quality overall has improved in the past 3 years.

The Chinese government pays great attention to environmental problems, and especially haze pollution due to an inadequate energy consumption structure. To this end, a series of haze pollution reduction policies, which include public participation in environmental protection, were formulated during the 18th National Congress of the Communist Party of China(Jia et al., 2019; Song et al., 2019). A growing body of literature documents qualitatively that PPEB has a highly positive impact on haze pollution regulation and, in turn, public health improvement as a result of complaints about environmental issues to governments and organizations connected to environmental protection (Drazkiewicz et al., 2015; Fu & Geng, 2019; Shen et al., 2019). The government has enacted measures to limit haze pollution and penalize the industrial emission of pollutants, based on public opinion, and consequently lead to the reduction of environmental pollutants and enhance PHL. In spite of the potentially significant role of PPEB in haze pollution reduction, however, there is limited empirical evidence regarding whether haze pollution is influenced by concerns about PPEB and little understanding of how to increase PPEB and PHL.

Different levels of economic development and environmental cognition determine the extent of PPEB in a region or country. China is a large developing country in the process of forming a market economy, with diverse ethnic groups and cultures. Therefore, each region—eastern, central, and western—distinctly differs in the amount of PPEB. The eastern region is a comparatively developed area, in which the public has a higher level of environmental culture and is more concerned with self-health status, which results in better PPEB. The western region is relatively lagging in economic development; there is less PPEB and serious haze pollution because of the presence of numerous highly polluting enterprises, many of which consume fossil energy. Haze pollution is more serious in the central region than western region, likely because economic development is slightly better in the former than the latter, but the PPEB level is still not higher than in the eastern region. Thus it is essential that each region explore the heterogeneous influence of PPEB on haze pollution and PHL, which can motivate the public to take PPEB more seriously, raise PPEB efficiency, and improve air quality and PHL.

This study provides empirical answers to the following research questions: (1) How does PPEB influence haze pollution and PHL? (2) What is the relationship between PPEB and haze pollution and PPEB and PHL? (3) Is there an inverted U- shaped or linear relationship between them? (4) Are there regional differences in this relationship?

As the survey by Fu and Geng (2019) demonstrates, the literature is surprisingly ambiguous regarding this relationship. Some qualitative research finds that there appears to be a linear relationship between PPEB and haze pollution (Wu et al., 2018), while others do not find a linear relationship. Do regional differences exist in these regions? To address this ambiguity, we first investigated the regional effects of PPEB on haze pollution governance (HPG) and public health in China using dynamic panel estimation. Thus, this study provides policy implications for public health improvement in China in association with enhanced PPEB and the abatement of haze pollution.

The aim of the present research is, therefore, to examine how PPEB influences haze pollution and PHL in China. To achieve these targets, based on an extended health production function, a STIRPAT model using four econometric techniques was employed to analyze panel data in China from 2000 to 2017 across 31 provinces. These provinces were divided into three regions—eastern, central, and western—based on location, geography, and economic development. We find an inverted U-shaped relationship between PPEB and haze governance and PPEB and PHL.

The rest of the paper is organized as follows. Section 2 reviews the literature on the effects of PPEB on haze pollution and PHL. Section 3 describes our main models, econometric methodology, and data sources. In Section 4, we present the empirical results. Section 5 discusses the empirical results of the estimations. Section 6 concludes and offers policy suggestions.

2. Literature review

The analysis of factors that affect haze pollution in the environmental economics field has always attracted a great deal of attention. Most empirical research on these issues in China and abroad argues that the relationship between environmental pollution and the level of socioeconomic development is complicated (Evans & Kantrowitz, 2002; Ji et al., 2018b). The first explanation assumes that haze pollution is mainly derived from an imbalance in the energy structure—specifically, the higher proportion of fossil energy in total consumption due to the imbalance of natural resources and constraints on the resource endowment based on energy economics (Bilgili et al., 2016; Lelieveld et al., 2015; Tong et al., 2016; Zhang et al., 2015). The second explanation attributes this issue to lower awareness of PPEB based on the theory of planned behavior (TPB), whereby individuals don't act 100% voluntarily, but rather in response to certain influences, and normative activation theory (NAT), which holds that behavior can be predicted based on personal norms and societal duties. (Ru et al., 2019; Xu et al., 2020). The third argues that economic growth in a country accompanies environmental pollution, and particularly in developing countries (Liu et al., 2019). The fourth presumes that urbanization could increase haze pollution to a certain extent (Qu et al., 2018; Sharma, 2011). The fifth involves the population factor based on the theory of demography (Ho, 2018). In this vein, it is worth mentioning that PPEB is the single most important factor with respect to improving PHL.

First, PPEB could motivate the public to attach importance to environmental improvement for PHL by popularizing PPEB in China, which could lower haze pollution and have a significant effect on improving fundamental air quality, and is thus conducive to PHL to a certain extent(Li et al., 2018; Qu & Yan, 2017). Second, an increasing amount of PPEB will restrict pollutant emissions by higher-polluting enterprises to a larger degree, which also motivates enterprises to consider green production technologies and continually implement technological innovations. In turn, this would lead to less pollution or zero pollution, and gradually remove the threat to PHL from companies' emissions, decrease death rates, and improve PHL(Chen et al., 2015). Third, PPEB could prompt governments to enact laws regarding PPEB to encourage the public to participate in environmental governance by pushing PPEB forward and improving air quality (Fu & Geng, 2019; Shen et al., 2019). For instance, Chengdu city in Sichuan province recently proposed a "dual path" to inclusive construction using low-carbon methods. These involve encouraging participation on a platform that connects the public with micro-enterprises that follow green and low-carbon practices to promote green and low-carbon construction. The effort can be summarized as "Everyone's attention, everyone's participation, everyone benefits," and would be conducted in urban areas to enhance air quality and, consequently, improve the PHL.

Considering the serious effects of haze pollution on public health, most studies have focused on the analysis of public health and air pollution. In contrast, few studies examine the relationship from the perspectives of both management and economics (Chen et al., 2020; Qu & Yan, 2015). In response to China's emerging environmental and public health problems, the attention of medical scholars has been drawn to the effects of environmental pollution on public health. In the literature, the relationship between pollution and health has been extensively researched by scholars from public health and medical fields (Chen et al., 2017; Eckelman & Sherman, 2016; Kan et al., 2012). McKenzie et al. (2012) review the literature on air pollution and human health in China from three perspectives—chronic health effects, acute health effects, and intervention effects—and find that the overwhelming majority of studies support the adverse effects of air pollution on health. Guarnieri and Balmes (2014) argue that power generation and traffic are the main sources of urban air pollution, and show that $PM_{2.5}$ has significant importance for public health. Air pollution is considered to be the largest environmental cause of disease and premature death around the world; for instance, diseases caused by pollution accounted for an estimated 9 million premature deaths in 2015 (Chen et al., 2016; Landrigan et al., 2018; Seaton et al., 1995). Héroux et al. (2015) quantify the health impacts of ambient air pollutants and show that directional causality exists between them. Their results form the scientific basis for policies designed to improve air quality and thereby decrease the disease burden related to air pollution in Europe.

The effects of economic growth on environmental pollution have become common ground for research by economists. A number of studies investigate the relationship between environmental pollution and the economic growth nexus using the framework of the environmental Kuznets curve (EKC) (Dinda, 2004; Gill et al., 2018; Qu et al., 2018). The EKC was derived from the original Kuznets curve, which examines the association between inequality and per capita income. Özokcu and Özdemir (2017) point out that at first, income inequality rises with an increase in per capita income, then declines when it reaches a critical value. Hence, the EKC hypothesis argues that environmentally polluting emissions increase with increased income, and when a given level of income is reached, these emissions start to reduce. Within this framework, emissions are specified as a function of income per capita, which supposes a unidirectional causality running from income to emissions. The validity of the EKC hypothesis and the causal association between emissions and income have been examined in many studies. However, The EKC hypothesis places emphasis on the objective factor of influential environmental pollution and fails to account for subjective factors such as PPEB. Omitting variables can be subjected to bias estimators in a model.

Theories on PPEB mainly involve public complaints about environmental pollution, daily low-carbon consumption behavior, and PPEB regulation based on TPB and NAT. Public complaints about environmental pollution are used as a proxy for PPEB. First, PPEB could limit the number of pollutants from enterprises with high pollution as a result of public complaints about pollutants, which have a positive effect on green production by energy transformation and technological innovation. Second, low-carbon public consumption behavior is the embodiment of PPEB, to a certain extent; it motivates the public to save on energy use and form good habits for low-carbon consumption in daily life. It also reminds people to care for the environment, reduce pollution and, as a result, influence PHL. Third, optimal guidelines for PPEB ensure the legality of public participation in environmental governance, which lays a solid foundation for PPEB. The goal is to alleviate haze pollution and improve PHL by clarifying the responsibility borne by the public, governments, and enterprises and constructing a mechanism for dialogue and consultation based on equality and cooperation.

In the past 20 years, environmentalism has become a major sociopolitical force in Chinese society, which one reason the environmental movement has received widespread support from the general public (Dunlap & Mertig, 2014). PPEB is a relatively new approach to environmental management that can improve the quality of environmental decision-making and sustainable development (Drazkiewicz et al., 2015; Reed, 2008; Rega & Baldizzone, 2015; Rowe et al., 2000). PPEB is also of crucial importance for the development of a healthy environmental governance system. However, public participation has not been well institutionalized in China, and the public’s role in environmental management is limited (Chen et al., 2015). A few scholars have investigated the correlation between PPEB and haze pollution and between PPEB and PHL, such as Brombal et al., 2017; Glucker et al., 2013; McKinley et al., 2017; and Yi et al., 2020. These studies find that PPEB helps reduce haze pollution and also argue that there appears to be a linear relationship between them. In representative studies, Li (2017) posits that local governments should pay attention to the role of PPEB in the environment, and Zhang et al. (2014) incorporates the theory of environmental public participation into the STIRPAT model and shows that there are significant regional disparities in the influences of PPEB on environmental quality. Specifically, the influence of environmental complaint letters on environmental quality is significantly positive in central China but nonsignificant in eastern or western

China. Shen et al. (2019) shows that the stronger the appeals to the public for environmental awareness, the greater the degree to which governments address environmental pollution. For instance, in Hebei and Shanxi, where environmental pollution problems are more serious, appeals to the public are relatively strong. Li et al. (2018) find that if government policies, the public, and enterprises jointly cooperate, air pollutants could effectively be alleviated and allow for sustainable development goals to be achieved.

The relationships between economic growth, environmental pollution, and public health have drawn great interest in recent years. Wu et al. (2017) use a computable general equilibrium (CGE) model to evaluate the effect of $PM_{2.5}$ on health on the national and provincial economies of China based on the latest nonlinear exposure-response functions, which show that a high $PM_{2.5}$ concentration in provinces has a seriously substantial impact on economics and PHL. Qu and Yan (2015) use panel data on 30 provinces in China from 1997 to 2010 to construct an entity fixed-effects model, and analyze the differences between the eastern, central, and western regions. They find a long equilibrium cointegration relationship between environmental pollution, economic growth, healthcare services, and public health; also, an inverted U-shaped curve is present between economic growth and public health in the eastern and central regions and the whole of China significantly.

Moreover, economic and social factors may also affect public health. Li et al. (2016) employ data on sulfur dioxide (SO_2) and inhalable particulate matter (PM_{10}) from January 2015 to June 2015 in 74 cities by constructing lowest and highest limit scenarios. They show that in both scenarios, the health-related economic losses caused by PM_{10} and SO_2 were 1.63% and 2.32% of GDP, respectively. Health and disease are determined by several factors, including housing, environmental exposure, education, and social and economic status. Therefore, to improve the population's health and health equity it is necessary to take intersectoral action and motivate social participation—goals that many Latin American countries have achieved (Andrade et al., 2015). Also, these studies demonstrate why PPEB has an important implication for haze pollution and PHL; however, the research is confined to the effects of objective factors on haze pollution and PHL The combination of objective and subjective factors, such as how PPEB affects haze pollution and PHL, is rarely examined empirically.

The main contributions of this paper are the following. First, the paper pioneers the development of an extended STIRPAT model and health function theory (Grossman, 1972) to study the relationship between PPEB and haze pollution and PPEB and PHL, given that PPEB is an increasingly important subject in environmental governance, and to put it into an integrated model framework. Second, this paper reports novel results regarding the heterogeneous impacts of PPEB on haze pollution and PHL and finds a nonlinear relationship in the full sample of China and the eastern, central, and western regions, respectively. Third, this paper makes an important contribution to the literature by examining the inverted U-shaped relationship between PPEB and haze pollution, PPEB and PHL, and urbanization and haze pollution and replacing sulfur dioxide, nitrogen oxide, and soot with $PM_{2.5}$ as the proxy for haze pollution. However, most previous studies use sulfur dioxide and nitrogen oxide as the proxy for haze pollution, given the difficulties accessing $PM_{2.5}$ data. This has an implication for recognizing the importance of PPEB with respect to environmental governance and the mechanism of PPEB that affects haze pollution and HPL in different regions. Thus, it is essential that governments formulate different policies for haze pollution governance and public health improvement for different regions.

3. Method and data

3.1. Model specification

Several studies on haze pollution, such as those by Shahbaz et al. (2016) and Shahbaz et al. (2017), include economic growth, urbanization rate, energy use, and total population variables in their empirical models, based on a STIRPAT model, to study the effects of these variables on air pollution. They typically find that these variables are importat and have a statistically significant impact on environmental quality. In addition, environmental pollution is the dominant factor in public health, and some scholars examine the relationship between the level of public health and influential factors—economic, environmental, social, etc. (Nasrollahi et al., 2018). The Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model, developed by York et al. (2003), is frequently used to analyze the effect of socioeconomic changes on environmental deterioration in previous studies. Also, the population is considered to be an explanatory variable in analyzing its effects on environmental conditions. This model rectifies the weakness of environmental Kuznets curves (EKC), in which income per capita is treated as an explanatory variable and CO_2 emissions per capita as explained variables. The STIRPAT model, in its general form, can be represented as follows:

$$E_t = \alpha(EC)^a P_t^b A_t^c T_t^d \mu_t \quad (1)$$

where *E* denotes energy pollutants, *EC* energy use, *P* population, *A* affluence (economic growth), and *T* technology; μ represents an error term. We further develop the model by incorporating PPEB. On the one hand, PPEB is an essential entity in supervising firms' polluting activities, and it is helpful for achieving the objective of reducing an enterprise's emissions and thus having a substantial effect on reducing pollution. On the other hand, PPEB urges governments to intensify pollution treatment and foster a sound environment for public health. PPEB embodies the public's concern about environmental pollution governance. According to our theoretical representation and data (Figs. 1 and 2), there is a nonlinear association between haze pollution and PPEB. In the early stage of haze pollution, citizens tend to pay more attention to the cost of participating in eco-environmental improvement than to the outcome of environmental pollution.

Also, a lengthy timeline is required for PPEB to have an impact on haze pollution—namely, the guaranteed time—and cannot on a shorter timeline. However, as PPEB reaches a certain scale, citizens may become more concerned with environmental quality, and the effect of PPEB on haze pollution could gradually become obvious. Therefore, the quadratic terms of PPEB are also incorporated in the regression equation to reflect the nonlinear shape. Haze pollution governance (HPG) in a country can be a clear indicator of aspects of environmental protection behavior, since the effective performance of HPG requires long-term environmentally friendly behavior by the public. The HPG of the previous period, therefore, is expected to have a positive effect on the current period (Jia et al., 2019; Yue et al., 2017). In addition, the population's death rate is considered to be a proxy for the level of public health (Dahal et al., 2018; Ford & Capewell, 2011; Qu & Yan, 2015). Therefore, taking the logarithm of (1) and adding the variable of PPEB, our empirical model of the influence of PPEB on HPG (Model PPEB-HPG) also includes some commonly used control variables so that the model can mitigate the potential for misspecification and biased estimation, as given by:

$$\ln pm25_{it} = \alpha_0 + \alpha_1 \ln pm25_{it-1} + \alpha_2 \ln ppeb_{it} + \alpha_3 \ln^2 ppeb_{it} + \alpha_4 \ln rgdp_{it} + \alpha_5 \ln insec_{it} + \alpha_6 \ln urbanp_{it} + \alpha_7 \ln^2 urbanp_{it} + \alpha_8 \ln popd_{it} + \mu_{it} \quad \text{(Model PPEB-HPG)}$$

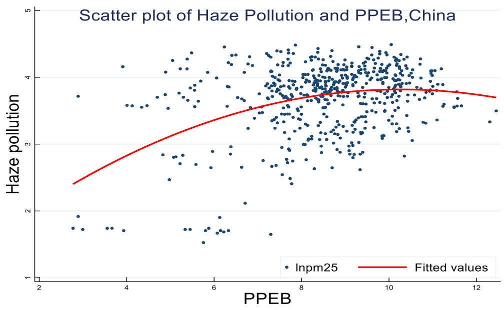

Fig.1. The trend of haze pollution and PPEB in China

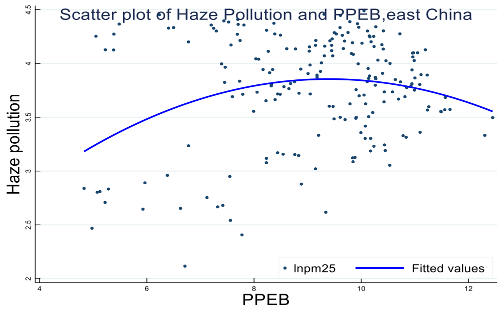

Fig.2. The trend of haze pollution and PPEB in eastern China

where *lnpm25* denotes haze pollution; *lnrgdp* measures income per capita, which is an economic factor; *lninsec* measures the proportion of fossil energy in total energy consumption, which is an energy factor; *lnurbanp* measures urbanization; *lnpopd* measures population density, which is a demographic factor. These five factors are the key variables that influence haze pollution (Qu et al., 2018; Qu & Yan, 2014; Yi et al., 2020). Provinces are denoted by the subscript *i* (*i*=1,2······31) and the time period is denoted by the subscript *t* (*t*=1,2······18). $\alpha_1, \alpha_2, \cdots \alpha_8,$ are the coefficients for the regressors estimated by the regression analysis. μ_{it} is an error term. In addition, referring to relevant research (Ji et al., 2018a; Qu & Yan, 2015), *T*, which is a technological factor, is not be incorporated into Model PPEB-HPG given that the proportion of fossil energy and income per capita is more closely related to technology.

The level of public health is mainly affected by serious haze pollution in China. Haze pollution has not only seriously affected the normal lives of residents, but also may post a threat to the PHL.

A theoretical health production function (HPF) was developed by Grossman (1972) and can be expressed as

$$H = F(x) \qquad (2)$$

where H is individual health level and x is a vector of individual inputs to the HPF. The vector elements mainly include nutrient intake, public goods use, income, time devoted to health-related procedures, education, and individual endowments such as genetic makeup, postnatal environment, etc.

This theoretical model was intended to be used for HPF analysis at the micro-level. However, our focus here is to analyze the HPF system at the macro-level. To change from micro to macro research, without losing the theoretical basis, vector elements X were represented by variables per capita and regrouped into subsectoral vectors of social, economic, and environmental factors as

$$h = F(Y, S, V) \qquad (3)$$

where Y is a series of economic variables per capita, S a series of social variables per capita, and V a vector of environmental factors per capita. In its scalar form, Equation 3 can be expressed as

$$h = f(y_1, y_2, \cdots y_n, s_1, s_2 \cdots s_m, v_1, v_2, \cdots v_l) \qquad (4)$$

where *h* represents an individual's health level proxied by life expectancy at birth, $(y_1, y_2, \cdots y_n) = Y$, $(s_1, s_2 \cdots s_m) = S$, $(v_1, v_2, \cdots v_l) = V$, and *n, m, l* represents the number of variables in each subgroup, respectively. Using calculus, model (4) can be changed into its explicit form and given as

$$h = \Omega \prod y_i^{\alpha_i} \prod s_j^{\beta_j} \prod v_j^{\gamma_j} \qquad (5)$$

where α_i, β_j, γ_k are elasticities. With respect to empirical research, the list of each subgroup's variables across different regions in the study may not necessarily be uniform, because these factors may partly be influenced by the specific culture and national environment. Behrman and Deolalikar (1988) emphasize that the model was built in empirical research to take a proper range of inputs into account, rather than those that are closely connected to public health or therapeutic measures in developed countries. Based on the above discussion and analysis, for our empirical analysis, the y_i variables are economic factors that are restricted to include income per capita; β_j variables are social factors that are restricted to population and the proportion of secondary industry; and $\gamma_k$variables are environmental factors—namely, urbanization and haze pollution. Taking the logarithm of (5) and rearranging it yields

$$ln\, health = ln\, \Omega + \sum \alpha_i (ln\, y_i) + \sum \beta_j (ln\, s_j) + \sum \gamma_k (ln\, v_k) \qquad (6)$$

where i=1, j=1,2, and k=1,2 and Ω is an estimate of the initial health stock of the region. Equation (6) lacks the subjective variables, such as PPEB; equation (6) is added into the factor of PPEB because PPEB has an important influence on the PHL. In addition, we have observed that the relationship between PPEB and the PHL is not linear based on data presentation, so we add the quadratic terms of PPEB to the model (Figs. 3 and 4). In addition, worse PHL in the previous period might lead to a higher death rate. Finally, the model with the impact of PPEB on PHL (Model PPEB-PHL) is developed as follows:

$$\ln death_{it} = \beta_0 + \beta_1 \ln death_{it-1} + \beta_2 \ln ppeb_{it} + \beta_3 \ln^2 ppeb_{it} + \beta_4 \ln pm2.5_{it} + \beta_5 \ln rgdp_{it} + \beta_6 \ln pdoc_{it} + \varepsilon_{it} \qquad \text{(Model PPEB-PHL)}$$

where *lndeath* measures PHL; *lnppeb* is the human factor; *lnpm2.5* measures HPG as an environmental factor; *lnrgdp* is an economic factor; and *lnpdoc* measures the factor of medical service. These four factors are the main factors that affect PHL (Eckelman & Sherman, 2016; Qu & Yan, 2014). Provinces are denoted by the subscript *i* (*i*=1,2······31), and the time period is denoted by the subscript *t* (*t*=1,2······18). $\beta_1, \beta_2, \cdots \beta_6$, are the coefficients of the regressors estimated by regression analysis. ε_{it} is an error term.

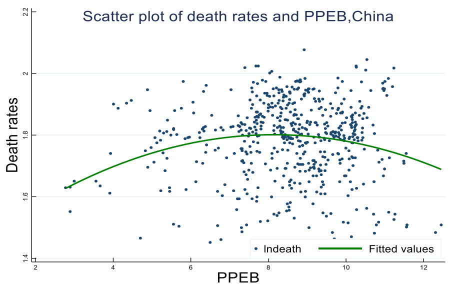

Fig.3. The trend of death rates and PPEB in China

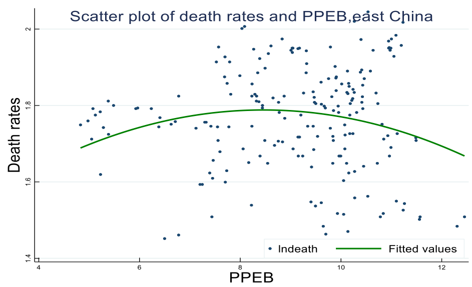

Fig.4. The trend of death rates and PPEB in eastern China

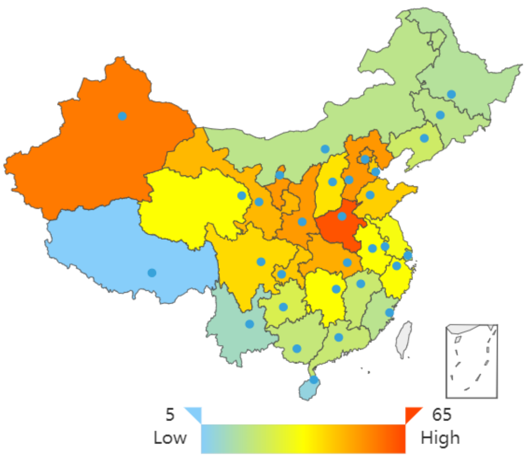

Fig.5. The distribution of $PM_{2.5}$ in each province, 2000

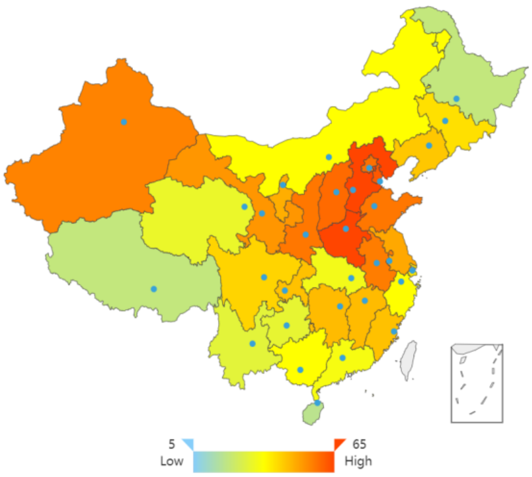

Fig.6. The distribution of $PM_{2.5}$ in each province, 2017

3.2. Measures and data source

In the PPEB-HPG model, *pm25* represents the extent of HPG, since $PM_{2.5}$ accounts for haze pollution that also includes other pollutants. *ppeb* represents PPEB, measured by the number of public environmental letters of complaint about environmental pollution, considering the availability of the data referring to relevant scholars (Liao, 2018; Wu et al., 2018). The variable *rgdp* represents real GDP per capita measured for per capita income. The variable *insec* represents the proportion of secondary industry to total GDP, measured as the energy use, since haze pollution as a result of energy consumption in the industrial sector—compared with agriculture and tertiary industries—is much higher. The variable *urbanp* represents the urbanization level in a country, which is measured by the ratio of urban population to the total population, in line with several studies (Ji et al., 2018b; Shahbaz et al., 2016). The variable *popd* represents population density, measured by the degree of population agglomeration. The number of people who immigrate from one place to another one will affect the energy consumption required to maintain normal activities—such as daily life, production, and traffic, which can give rise to haze pollution emissions. Consequently, increasing the population could influence haze pollution (Cao et al., 2018; Liu et al., 2017).

In the PPEB-PHL model, *pm25, ppeb*, and *rgdp* are the same as in the PPEB-HPG model. The variable *pdoc* represents the number of doctors per 10,000 population. This variable is measured by the level of medial service in a country or a region, according to Qu and Yan (2015) and Cesari et al. (2016).

The dataset is a balanced panel that consists of observations for 31 provinces covering the period 2000-2017, with a sample of 549 observations. China is divided into three regions (see Table 1), according to Shi et al. (2010) and Qu et al. (2017). $PM_{2.5}$ data are from the Socioeconomic Data and Applications Center (sedac) at Columbia University. The distribution of $PM_{2.5}$ is given by Figs. 5 and 6 for 2010 and 2017, respectively; we find that the concentration of $PM_{2.5}$ in 2017 is XXXX than in 2010. Province-level data are collected from the China Statistical Yearbook, China Environmental Statistical Yearbook, Statistical Yearbooks of each province, and a compilation of statistics from the New China database for 60 year The variable *pm25* denotes the concentration of haze emissions per year (unit: $\mu g/m^3$); *ppeb* denotes the number of public letters complaining about environmental issues (unit: number/year); *inse*c denotes the share of secondary industry to total GDP (unit: %); the unit for *urbanp* is also percentage; population density is obtained by dividing the population by the total area in each province (unit: %); and *pdoc* is the number of doctors per 10,000 population (unit: number/10,000population). To ensure comparability, real GDP per capita (*rgdp*) is calculated at constant 1990 ¥, and all variable are expressed in natural logarithms. Descriptive statistics and the correlation matrix are presented in Tables 2 and 3.

Table 1

Distribution of the 31 administrative regions in the three regios of China.

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

Table 2 presents descriptive statistics of all variables, on average, after taking the natural logarithm of haze pollution, PHL, and PPEB for the whole country, eastern, central, and western regions, respectively; haze pollution is 3.680, 3.768, 3.801, and 3.518; PHL is 1.785, 1.765, 1.800, and 1.793; and PPEB is 8.542, 9.118, 8.656, and 7.938. For the whole country, the standard deviation of PPEB is 1.592 and the minimum and maximum are 2.773 and 12.452, respectively, which means that the difference in PPEB is great for the whole of China. The standard deviations reveal that the data for all series are fairly dispersed around the mean. This allows us to proceed with the data to conduct further estimation for the whole of China, eastern China, central China, and western China.

Table 2

Descriptive statistics for all variables in the study.

Variable	Obs	Mean	Std.Dev.	Min	Max	Variable	Obs	Mean	Std.Dev.	Min	Max
	The full sample in China							**Eastern China**			
lnpM25	558	3.680	0.550	1.526	4.49	lnpM25	198	3.768	0.501	2.116	4.49
lnPPEB	558	8.542	1.592	2.773	12.452	lnPPEB	198	9.118	1.625	4.828	12.452
lnPPEB2	558	75.496	25.459	7.687	155.063	lnPPEB2	198	85.763	27.903	23.313	155.063

lnrgdp	558	8.208	0.478	7.223	9.714	lnrgdp	198	8.567	0.511	7.811	9.714
lninsec	558	3.812	0.294	2.944	8.535	lninsec	198	3.803	0.442	2.944	8.535
lnurbanp	558	3.844	0.312	2.941	4.495	lnurbanp	198	4.084	0.26	3.261	4.495
lnpopd	558	5.272	1.483	0.742	8.256	lnpopd	198	6.409	0.723	5.447	8.256
lndocp	558	2.884	0.342	1.099	4.069	lndocp	198	3.028	0.369	2.339	4.069
lndeath	558	1.785	0.127	1.437	2.077	lndeath	198	1.765	0.138	1.437	2.045
Variable	Obs	Mean	Std.Dev.	Min	Max	Variable	Obs	Mean	Std.Dev.	Min	Max
		Central China						**Western China**			
lnpM25	144	3.801	0.365	2.797	4.482	lnpM25	216	3.518	0.649	1.526	4.308
lnPPEB	144	8.656	1.049	4.883	10.343	lnPPEB	216	7.938	1.654	2.773	11.55
lnPPEB2	144	76.027	17.028	23.842	106.975	lnPPEB2	216	65.729	24.081	7.687	133.406
lnrgdp	144	8.051	0.274	7.498	8.522	lnrgdp	216	7.983	0.34	7.223	8.732
lninsec	144	3.868	0.14	3.239	4.119	lninsec	216	3.783	0.168	3.016	4.067
lnurbanp	144	3.797	0.215	3.144	4.084	lnurbanp	216	3.656	0.264	2.941	4.16
lnpopd	144	5.531	0.58	4.383	6.366	lnpopd	216	4.056	1.509	0.742	5.923
lndocp	144	2.816	0.275	2.238	3.258	lndocp	216	2.797	0.313	1.099	3.34
lndeath	144	1.800	0.092	1.556	1.985	lndeath	216	1.793	0.134	1.449	2.077

The correlation matrix is presented in Table 3. The correlation between PPEB and HPG is positive, while the correlation between the quadratic term of PPEB2—namely, the quadratic term of PPEB—is negative. The association between public health and the variable for the quadratic term of PPEB is negative, and then the first power of PPEB is positive. The correlation between the number of doctors per 10,000 and PHL is negative, and the correlation between GDP per capita and public health is positive.

Table 3

Correlation between the variables used in the regression models for the whole of China.

	lnpm25	lnppeb	lnppeb2	lnrgdp	lninsec	lnurbanp	lnpopd	lndocp	lndeath
lnpm25	1								
lnppeb	0.3457	1							
lnppeb2	-0.1141	0.9882	1						
lnrgdp	0.2851	0.0728	0.0845	1					
lninsec	0.322	0.2377	0.2276	-0.0144	1				
lnurbanp	0.3348	0.2079	0.2103	0.8684	0.0631	1			
lnpopd	0.5062	0.4802	0.4753	0.3649	0.0959	0.5117	1		
lndocp	0.2519	-0.012	-0.0376	0.7121	-0.0833	0.6714	0.1532	1	
lndeath	0.0748	0.0363	-0.0073	-0.3491	0.1096	-0.2395	0.1495	-0.2777	1

3.3. Estimation and endogeneity issues

3.3.1. Estimation procedures

Our empirical strategy is mainly based on the system generalized method of moments (GMM). This GMM estimator is particularly suitable in this context. Besides controlling for province-specific effects, it retains the cross-province dimension of the data, which could be lost when the data is estimated using only the first differenced equation. Furthermore, using the GMM estimator, reverse causality and endogeneity issues are widely addressed.

A few main variables might be endogenous because of inverse causation between the explained variable and the explanatory variable in our models. For example, the literature shows that feedback effects may exist between PPEB and HPG, and PPEB and PHL. The empirical and theoretical literature has shown that differences in PPEB demonstrate a considerable part of cross-province differences in HPG. The evidence further shows that the broader and more in-depth PPEB effectively mitigates HPG and ameliorates the environment; thus it improves public health. Conversely, a case has been made whereby PPEB is affected by HPG and public health. Moreover, omitted unobservable and observable variable bias, which also produces endogeneity, may be an issue. Thus, a dynamic system GMM model (GMM-SYS) is employed to address potential endogeneity and ensure the reliability of our estimates for our model. The GMM estimation for the dynamic panel can be separated into two-step and one-step estimation according to different choices of the weight matrix. Bond (2001) finds that the standard error of the two-step GMM estimation value within limited samples will have an obvious downward bias. Furthermore, Roodman (2009) argues that system GMM produces by default a high number of instruments with an increasing number of periods, which can cause overfitting endogenous variables and render model specification estimations weak. Hence, for the model with fewer provinces and a longer time span (eastern, central, and western regions), one-step system GMM is employed—whereas for the model with a larger number of provinces and a shorter time span (31 provinces and 18 years), two-step system GMM is employed.

3.3.2. Endogeneity issues

It is difficult to address endogeneity issues using two-stage least squares with searching for instrumental variables that are not easily obtained. We adopted a dynamic panel model to address issues of endogeneity, following several studies (Bhattacharya et al., 2017). The GMM model may be written as follows:

$$Y'_{kt} = \delta_1 Y'_{kt-1} + \delta_2 Z'_{kt} + \vartheta_i + \epsilon_t + \varepsilon'_{it} \quad (7)$$

where Y'_{kt} denotes $ln\,pm25_{it}$ and $ln\,death_{it}$. Y'_{kt-1} represents the lagged explained variable of $ln\,pm25_{it}$ and $ln\,death_{it}$ in PPEB-HPG and PPEB-PHL models, respectively. Z'_{kt} is a vector of control variables. ϑ_i represents the unobserved term of fixed effect, ϵ_t is time effects, and ε'_{it} represents an error term. δ_1, δ_2 are respective elasticities with respect to the PPEB-HPG and PPEB-PHL models. Variables are taken in logarithm for estimation purposes. Rewriting equation (7) as a difference equation yields

$$Y'_{kt} - Y'_{kt-1} = \delta_1 (Y'_{kt-1} - Y'_{kt-2}) + \delta_2 (Z'_{kt} - Z'_{kt-1}) + \varepsilon'_{it} - \varepsilon'_{it-1} \qquad (8)$$

Differencing leads to unbiased estimates. In particular, unobserved province (ϑ_i) and time (ϵ_t) fixed effects that are likely sources of omitted variable bias may be eliminated using differencing methods. Based on Arellano and Bond (1991), to correct issues of potential endogeneity bias and the correlation between an explained variable and error terms, the regressor's lagged levels are used as instruments; this is often considered to be the first difference GMM (GMM-DIF) estimation, assuming weak regressors' exogeneity and the noncorrelation of error terms. Based on this, Blundell and Bond (1998) suggest that the estimator of GMM-DIF may cause biased estimates, given the existence of weak instruments that arise from lagged variables under the condition of persistent explanatory variables. Blundell and Bond (1998) also demonstrate that the GMM-SYS estimator is more efficient than that of the GMM-DIF. Generally speaking, GMM-SYS estimators produce instruments that can be good predictors for endogenous variables, and thus perform better compared with the GMM-DIF estimator under the condition of persistent series (Bhattacharya et al., 2017; Blundell & Bond, 1998).

This paper uses one-step and two-step estimators, consistent with Roodman (2009), to run the regressions using STATA 16. To be consistent, the estimator must pass the Hansen J-test of overidentifying restriction and should have no second-order serial correlation within the differencing error term for the estimator (Islam & McGillivray, 2020; Uddin et al., 2017). In GMM-SYS estimations, the joint validity of all instruments is examined using overidentifying restriction tests that work with the null hypothesis, in which the overidentifying restrictions are valid. The second-order autocorrelations test finds no autocorrelation for the null hypothesis, or the error term is serially correlated. We conducted these required tests in order to correct the validity of the models. Tables 6 and 7 list the estimation results at the bottom. Specifically, the null hypothesis—that the full set of orthogonality conditions are valid—cannot be rejected. In the first-differenced error terms, given the p-values for the autocorrelation test, the null hypothesis of no second-order serial correlation cannot be rejected as well.

4. Empirical results

4.1. Panel unit root test

Before examining the cointegration analysis, it is necessary to examine a panel unit root for all regression variables by identifying the existence of unit-roots in order to avoid any false results and determine the feasibility of panel cointegration. In this paper, we conduct four types of unit root tests—those of LLC (Levin et al., 2002) and IPS (Im et al., 2003). In addition, we follow the procedures of Maddala and Wu (1999) and Choi (2001) by using the nonparametric unit root test of the Fisher-ADF and Fisher-PP statistics.

Table 4 lists test results for the panel unit root. The four tests have the null hypothesis whereby all of the panels contain a unit root. The statistics solidly confirm that each variable in this regression model is the I(1) process. Therefore, a cointegration relationship that exists among the variables is examined using the panel cointegration method.

Table 4

Panel data unit root results.

	LLC Test		IPS Test		Fisher- ADF		Fisher-PP	
	At level	At first difference	At level	At first difference	At level	At first difference	At level	At first difference
The whole of China								
lnpm25	-2.280	-5.338***	0.887	-6.890***	59.218	163.482 ***	128.757	443.935 ***
	(0.011)	(0.000)	(0.813)	(0.000)	(0.577)	(0.000)	(0.000)	(0.000)
lnppeb	-1.091	-2.471***	-1.630	-5.616***	73.761	130.952 ***	123.953	471.100 ***
	(0.138)	(0.007)	(0.052)	(0.000)	(0.164)	(0.000)	(0.000)	(0.000)
lnppeb2	-5.404	-22.836***	-4.835	-20.242	116.083	414.653 ***	112.511	773.493 ***
	（0.000）	(0.000)	（0.000）	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lninsec	-1.752	-10.129***	5.054	-7.584***	37.573	159.113 ***	28.321	303.628 ***
	(0.040）	(0.000)	(1.000)	(0.000)	(0.994)	(0.000)	(1.000)	(0.000)
lnurbanp	-3.763	-7.118***	-0.445	-6.551***	81.556	151.768 ***	106.860	384.023 ***
	(0.000)	(0.000)	(0.328)	(0.000)	(0.049)	(0.000)	(0.000）	(0.000)
lnrgdp	3.603	-7.107***	4.355	-3.419***	22.771	106.076 ***	24.032	189.112 ***
	(1.000）	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000）
lnpopd	3.253	-5.266 ***	4.8902	-4.934***	65.382	152.955 ***	48.452	160.250 ***
	(0.999)	(0.000)	(1.000)	(0.000)	(0.3602)	(0.000)	(0.896)	(0.000)

lndocp	7.148	-17.213 ***	8.126	-15.342***	31.169	324.478 ***	32.503	499.742 ***
	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)	(0.999)	(0.000)
lndeath	-4.041	-20.431***	-3.302	-18.924***	103.100	391.060 ***	111.771	820.897 ***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Eastern China								
lnpm25	0.452	-0.860	1.998	-3.966 ***	8.148	53.568 ***	46.001	166.023 ***
	(0.675)	(0.195)	(0.977)	(0.000)	(0.997)	(0.000)	(0.002)	(0.000)
lnppeb	0.180	-0.558 ***	-0.985	-2.675 ***	26.095	39.646 ***	39.545	159.762 ***
	(0.571)	(0.289)	(0.162)	(0.004)	(0.248)	(0.012)	(0.122)	(0.000)
lnppeb2	0.779	-2.909 ***	-0.31708	-5.040 ***	21.125	64.662 ***	29.028	202.056 ***
	(0.7822)	(0.002)	(0.3756)	(0.000)	(0.513)	(0.000)	(0.144)	(0.000)
lninsec	-4.282	-6.076 ***	1.164	-4.892 ***	22.517	63.343 ***	15.238	133.922 ***
	(0.000)	(0.000)	(0.878)	(0.000)	(0.878)	(0.000)	(0.852)	(0.000)
lnurbanp	-3.745	-7.6489 ***	0.640	-4.293 ***	24.316	56.325 ***	32.861	148.512 ***
	(0.000)	(0.000)	(0.739)	(0.000)	(0.331)	(0.000)	(0.064)	(0.000)
lnrgdp	1.023	-5.486 ***	2.343	-2.957 ***	8.468	47.008 ***	15.685	90.065 ***
	(0.867)	(0.000)	(0.990)	(0.002)	(0.996)	(0.002)	(0.831)	(0.000)
lnpopd	-2.059	-4.843 ***	2.484	-4.213 ***	19.251	56.282 ***	3.932	51.998 ***
	(0.020）	(0.000)	(0.994)	(0.000)	(0.630)	(0.000)	(1.000)	(0.000)
lndocp	2.915	-12.801 ***	3.090	-13.071 ***	24.656	161.767 ***	26.199	283.177 ***
	(0.998)	(0.000)	(0.999)	(0.000)	(0.314)	(0.000)	(0.243)	(0.000)
lndeath	-0.506	-12.308 ***	-0.978	-11.164 ***	29.625	136.238 ***	32.687	159.283 ***
	(0.307)	(0.000)	(0.164)	(0.000)	(0.128)	(0.000)	(0.066)	(0.000)
Central China								

lnpm25	-1.103	-3.526***	0.207	-2.856***	16.919	35.330***	26.748	103.288***
	(0.135)	(0.002)	(0.582)	(0.002)	(0.391）	(0.004)	(0.044)	(0.000)
lnppeb	-0.746	-0.765	0.143	-3.265***	12.780	36.963***	22.977	143.848***
	(0.228)	(0.222)	(0.557)	(0.001)	(0.689)	(0.002)	(0.114)	(0.000)
lnppeb2	-2.431	-9.649***	-1.946	-9.417***	26.799	98.240***	26.761	128.699***
	(0.008)	(0.000)	(0.026)	(0.000)	(0.044)	(0.000)	(0.044)	(0.000)
lninsec	0.427	-3.121***	3.004	-2.375***	3.352	33.077***	1.587	46.103***
	(0.665)	(0.001)	(0.999)	(0.009)	(1.000)	(0.007）	(1.000)	(0.000)
lnurbanp	-0.620	-2.376***	-0.293	-3.185***	18.180	39.638***	36.878	105.604***
	(0.268)	(0.009)	(0.615)	(0.001)	(0.314)	(0.001)	(0.002)	(0.000)
lnrgdp	2.114	-4.467***	2.482	-2.010**	3.830	27.579**	1.968	48.937***
	(0.983)	(0.000)	(0.994)	(0.022)	(0.999)	(0.035)	(1.000)	(0.000)
lnpopd	3.695	-5.487***	2.002	-4.299***	17.059	48.151***	18.041	48.322***
	(1.000)	(0.000)	(0.977)	(0.000)	(0.382)	(0.000)	(0.322)	(0.000)
lndocp	5.075	-7.907	6.235	-5.220***	0.992	59.921***	3.095	85.600***
	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)
lndeath	-1.979	-9.759***	-1.672	-9.337***	24.938***	100.207***	24.786	173.389***
	(0.024)	(0.000)	(0.047)	(0.000)	(0.071)	(0.000)	(0.074)	(0.000)
Western China								
lnpm25	-0.428	-2.872***	1.655	-4.871***	25.067	88.898***	72.749	269.311***
	(0.335)	(0.002)	(0.951)	(0.000)	(0.947)	(0.000)	(0.000)	(0.000)
lnppeb	-0.341	-0.920	-0.656	-4.154***	38.874	76.608***	62.523	303.610***
	(0.367)	(0.179)	(0.256)	(0.000)	(0.432)	(0.000)	(0.007)	(0.000)
lnppeb2	-4.228	-14.929***	-4.156	-12.768***	56.043	164.111***	56.722	442.738***

	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lninsec	-3.526	-6.622 ***	2.835	-5.263 ***	25.868	96.420 ***	16.825	180.024 ***
	(0.998)	(0.000)	(0.998)	(0.000)	(0.933)	(0.000)	(0.999)	(0.000)
lnurbanp	-2.622	-6.890 ***	0.677	-5.333 ***	42.495	95.961 ***	69.739	254.117 ***
	(0.004)	(0.000)	(0.751)	(0.000)	(0.284)	(0.000)	(0.001)	(0.000)
lnrgdp	2.185	-6.955 ***	3.393	-3.554 ***	12.298	74.587 ***	17.653	139.002 ***
	(0.986)	(0.000)	(0.100)	(0.000)	(1.000)	(0.000)	(0.998)	(0.000)
lnpopd	4.517	-0.144	3.833	-0.434	29.072	48.523 ***	26.478	59.929 ***
	(1.000)	(0.443)	(1.000)	(0.332)	(0.217)	(0.002)	(0.329)	(0.000)
lndocp	4.518	-9.085 ***	5.011	-7.959 ***	5.522	102.791 ***	3.208	130.966 ***
	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)
lndeath	-4.413	-13.225 ***	-3.035	-12.112 ***	48.537	154.615 ***	54.297	488.225 ***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)

Notes: Unit root tests are estimated using constant and trend variables; '***' indicates 1% significance level.

4.2. Panel cointegration test

In this section, we examine whether there is a stable equilibrium relationship between the explained variable and the explanatory variables that were proposed by Pedroni (Pedroni, 1999, 2001, 2004) and Kao (1999). The results show that the statistics reject the null hypothesis of non-cointegration at 1% and 5% levels of significance in the panel cointegration test (Table 5). This indicates that all of the variables have a long-run stable relationship. Also, combined with the panel nonparametric (t-statistic) and parametric (ADF-statistic) statistics, they are more reliable based on the constant plus time trend Pedroni (1999). Therefore, in the panel data sets, we can obtain a strong conclusion that there is a long-run cointegration within our variables.

Table 5

Panel cointegration results test.

		The whole of China		Eastern China		Central China		Western China	
Model PPEB-HPG		Test statistic	Prob	Test statistic	Prob	Test statistic	Prob	Test statistic	Prob
With-Dimension									
	Deterministic intercept	-3.040	0.999	-0.887	0.812	-1.766	0.961	-2.334	0.990
Panel v-Statistic	Deterministic intercept and trend	-5.306	1.000	-2.027	0.979	-2.839	0.998	-3.862	1.000
	No intercept or trend	-2.227	0.987	-0.249	0.598	-1.432	0.924	-1.783	0.963
	Deterministic intercept	6.652	1.000	0.756	0.775	2.164	0.985	2.963	0.999
Panel rho-Statistic	Deterministic intercept and trend	5.583	1.000	1.881	0.970	3.163	0.999	4.086	1.000
	No intercept or trend	2.203	0.986	-0.135	0.446	1.353	0.912	2.042	0.979
	Deterministic intercept	-6.925	0.000	-11.340	0.000	-1.682	0.046	-5.305	0.000
Panel PP-Statistic	Deterministic intercept and trend	-12.455	0.000	-13.958	0.000	-3.395	0.000	-6.036	0.000
	No intercept or trend	-7.782	0.000	-9.535	0.000	-1.684	0.046	-4.095	0.000
	Deterministic intercept	-3.209	0.001	-5.652	0.000	-1.622	0.052	-3.640	0.000
Panel ADF-Statistic	Deterministic intercept and trend	-5.264	0.000	-4.904	0.000	-2.544	0.006	-2.533	0.006
	No intercept or trend	-5.543	0.000	-6.076	0.000	-1.745	0.041	-3.269	0.001
Between-Dimension									
	Deterministic intercept	8.484	1.000	2.480	0.993	3.130	0.999	3.991	1.000
Group rho-Statistic	Deterministic intercept and trend	7.324	1.000	3.424	1.000	4.211	1.000	5.054	1.000
	No intercept or trend	4.233	1.000	1.545	0.939	2.534	0.994	3.255	0.999
	Deterministic intercept	-18.751	0.000	-11.476	0.000	-1.119	0.132	-7.221	0.000
Group PP-Statistic	Deterministic intercept and trend	-14.574	0.000	-12.350	0.000	-5.209	0.000	-7.347	0.000
	No intercept or trend	-11.104	0.000	-9.738	0.000	-1.164	0.122	-7.574	0.000
Group ADF-Statistic	Deterministic intercept	-4.284	0.000	-7.395	0.000	-1.947	0.026	-4.953	0.000
	Deterministic intercept and trend	-7.292	0.000	-6.270	0.000	-2.703	0.003	-3.510	0.000

	No intercept or trend	-8.148	0.000	-7.965	0.000	-1.715	0.043	-4.070	0.000
Kao Test	Deterministic intercept	-6.936	0.000	-7.767	0.000	-3.265	0.001	-3.273	0.005
Model PPEB-PHL									
With-Dimension									
Panel v-Statistic	Deterministic intercept	-2.969	0.999	-0.151	0.560	-0.526	0.701	-2.855	0.998
	Deterministic intercept and trend	5.250	1.000	-0.444	0.672	-1.824	0.966	-4.410	1.000
	No intercept or trend	-4.893	1.000	-0.956	0.831	-1.712	0.957	-3.366	1.000
Panel rho-Statistic	Deterministic intercept	1.276	0.899	0.802	0.789	0.870	0.808	0.694	0.756
	Deterministic intercept and trend	3.260	0.999	2.088	0.982	1.909	0.972	1.888	0.971
	No intercept or trend	2.723	0.997	1.061	0.856	1.170	0.879	1.785	0.963
Panel PP-Statistic	Deterministic intercept	-8.530	0.000	-2.705	0.003	-5.369	0.000	-6.227	0.000
	Deterministic intercept and trend	-11.089	0.000	-4.163	0.000	-6.312	0.000	-7.570	0.000
	No intercept or trend	-0.324	0.373	-1.298	0.097	-0.303	0.381	-0.061	0.476
Panel ADF-Statistic	Deterministic intercept	-6.892	0.000	-1.576	0.058	-1.000	0.000	-4.994	0.000
	Deterministic intercept and trend	-7.739	0.000	-3.161	0.001	-3.663	0.000	-5.328	0.000
	No intercept or trend	0.533	0.703	0.195	0.577	-0.225	0.411	0.408	0.658
Between-Dimension									
Group rho-Statistic	Deterministic intercept	3.821	1.000	2.177	0.985	2.015	0.978	2.412	0.992
	Deterministic intercept and trend	5.351	1.000	3.011	0.999	2.800	0.997	3.431	1.000
	No intercept or trend	4.099	1.000	2.375	0.991	1.930	0.973	2.739	0.997
Group PP-Statistic	Deterministic intercept	-11.712	0.000	-4.246	0.000	-7.217	0.000	-8.866	0.000
	Deterministic intercept and trend	-15.200	0.000	-7.754	0.000	-9.863	0.000	-8.954	0.000
	No intercept or trend	-4.319	0.000	-3.487	0.000	-0.642	0.260	-3.079	0.001
Group ADF-Statistic	Deterministic intercept	-5.859	0.000	-1.811	0.035	-4.215	0.000	-4.242	0.000

	Deterministic intercept and trend	-6.860	0.0000	-3.661	0.000	-3.786	0.000	-4.429	0.000
	No intercept or trend	-1.656	0.049	-0.787	0.216	-1.702	0.044	-0.517	0.303
Kao Test	Deterministic intercept	-3.452	0.000	-0.639	0.261	-3.485	0.000	-4.716	0.000

Note: *, **, ***indicates rejection of the null hypothesis of non-cointegration at the 10%, 5%, and 1% level of significance, respectively.

4.3. Estimations with the PPEB-HPG model for the full sample

For empirical purposes, regressions are run for the entire sample and estimation across regions. The results of these models are reported and discussed below.

Results for the full sample of 31 provinces and the eastern, central, and western regions are presented in Table 6. The PPEB-HPG model is presented for the POLS, FE-effects, and RE-effects estimates (Columns 1-3), while the last column (Column 4) provides system GMM estimators. For the PPEB-HPG model, the coefficients of GDP per capita, urbanization, fossil energy consumption, and population are significantly strong and positive across various estimation techniques. According to the discussion in the prior section, we find system GMM estimates to be consistent for both the PPEB-HPG and PPEB-PHL models and verify the validity of the instruments using estimations for autocorrelation and overidentification.

Based on the system GMM results in the PPEB-HPG model, we estimate the dynamic model of the inverted U relationship in the fourth column of the table. We first perceive that the coefficient for the *lnppeb* variable is significantly positive and that of *lnppeb2* is negative significantly and consistently across all estimations. These results thus support the existence of an inverted U-shaped relationship between $PM_{2.5}$ emissions and PPEB in China, which indicates that $PM_{2.5}$ emissions initially increase and then decrease after reaching a turning point in PPEB. Second, coefficients for the lagged explained variable are highly and significantly positive in regressions, which implies that emissions of $PM_{2.5}$ are positively serially correlated and hence warrant this dynamic specification in our study. Moreover, consistent with prior studies(Cao et al., 2016; Cheng et al., 2017; Liu et al., 2017), the signs for fossil energy use, GDP per capita, and population density are positive and significant at the 1% level. Specifically, at the 1% level of significance, a 1% increase in fossil energy consumption is associated with a 0.188% increase in HPG. We are further aware that both GDP per capita and population density are positively associated with HPG, but the effect of GDP per capita appears to be relatively stronger than that of population density. In this respect, a 1% increase in GDP per capita and population density is related to a 0.348% and 0.102% increase in HPG, respectively. In addition, we note that the coefficients for urbanization are significantly positive, but the coefficients for *lnurbanp2* are significantly negative; this suggests the existence of an inverse U-shaped relationship between $PM_{2.5}$ emissions and urbanization (Wang et al., 2018).

4.4 Estimations with the PPEB-HPG model for the three regions

To investigate the differences between the impact of PPEB on HPG in different regions and to conduct robustness tests, we estimated similar regressions for the three regions—eastern, central, and western. The estimated results in each region in the PPEB-HPG model in Table X are presented. For each region, four models are employed, The first model uses the POLS method, the second fixed effects, the third random effects, and the fourth Sys-GMM.

As shown in models (ii)-(iv) of Table 6, we notice that the coefficients for *lnppeb* and *lnppeb2* from the four methods is significantly positive and negative, respectively, at the 10% confidence level in each region, which demonstrates that there is an inverted U-shaped relationship between PPEB and HPG for these regions. These findings suggest that PPEB plays an important role in $PM_{2.5}$ pollution governance across regions to the extent that PPEB gradually rises spontaneously with the development of a country and PPEB could promote the reduction in $PM_{2.5}$ pollution, although PPEB initially leads to an increase in $PM_{2.5}$. More specifically, $\frac{\partial lnpm25}{\partial lnpub} = \alpha_{1i} - \alpha_{2i} lnpub$, where i =1, 2, 3, represents the eastern, central, and western regions, respectively. We calculate and get *lnppeb* 13.671 in the eastern region, 12.417 in the central region, and 10.513 in the western region, while the scale of PPEB still doesn't reach the turning point, according to Table 1. The average value of PPEB is less than that at the turning point. This result shows that the scale of PPEB is highest in the eastern region, second highest in the central, and lowest in the western. The reasons lie in the fact that there is a higher level of economic development and environmental culture in the eastern region than the central or western regions . People who have more knowledge about $PM_{2.5}$ pollutants' harmful effects on public health in the eastern region can be proactive with respect to environmental protection compared with those in the central and western regions. The value of $lnpm25_{t-1}$ (0.594) in the eastern region, $lnpm25_{t-1}$ (0.326) central region, and $lnpm25_{t-1}$ (0.493) in the western region implies that $PM_{2.5}$

pollution governance is corrected by 59.4%, 32.6%, and 49.3%, respectively, each year. As noted previously, there is also an inverted U-shaped relationship between HPG and urbanization, except in the eastern region. This, of course, relies on the fact that China's urbanization level tends to be ladder-like in each region: higher in the east, lower in the west, and intermediate in the central region, and the level of urbanization in eastern China has passed the inflection point out-of-the sample; those of the central and western regions have not passed this inflection point. Also, we notice that the coefficient of *lninsec* is positively related to HPG. Specifically, at the 10% significance level, a 1% increase in fossil energy is related to a 0.119%, 0.427%, and 0.651% increase in haze pollution in the eastern, central, and western region, respectively. The coefficient for the western region is more than three times that of the central region and five times that of the eastern region. This indicates that the proportion of fossil energy is much higher in the western region than the eastern and central regions. GDP per capita is positive and significantly related to haze pollution at the 5% and 10% level, except in the eastern and central regions. Finally, the coefficient for population density shows that population density has a significantly positive effect on haze pollution at the 10% level across three regions. A 1% increase in population density raises haze pollution by 0.104%, 0.383%, and 0.052% for the eastern, central, and western region, respectively.

Table 6

Results for the PPEB-HPG model.

	The whole of China (i)				Eastern China (ii)			
	Pooled OLS	Fixed effect	Random effect	Sys-GMM	Pooled OLS	Fixed effect	Random effect	Sys-GMM
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
lnpm25					lnpm25			
lnpm25t-1				0.474				0.594
				(0.000)				(0.000)
lnppeb	0.379***	0.325***	0.216***	0.211***	0.345*	0.168*	0.047*	0.246**

	(0.000)	(0.000)	(0.000)	(0.000)	(0.100)	(0.100)	(0.111)	(0.015)
lnppeb2	-0.238***	-0.348***	-0.245***	-0.012***	-0.019*	-0.015*	-0.020*	-0.009**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.100)	(0.100)	(0.100)	(0.09)
lninsec	0.381***	0.124***	0.148***	0.188***	0.287*	0.092*	0.063*	0.119*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.100)	(0.100)	(0.100)	(0.100)
lnurbanp	8.652***	6.473***	5.673***	4.704***	0.475	0.710*	(1.160)	0.061
	(0.000)	(0.000)	(0.000)	(0.000)	(0.231)	(0.100)	(0.200)	(0.112)
lnurbanp2	-1.234**	0.904**	-0.878**	-0.673***	-0.174	-0.127	-0.102	-0.066
	(0.050)	(0.050)	(0.050)	(0.000)	(0.251)	(0.213)	(0.110)	(0.210)
lnrgdp	0.697***	0.324***	0.491***	0.348***	0.685	0.261	0.275	0.681
	(0.000)	(0.000)	(0.000)	(0.000)	(0.120)	(0.114)	(0.050)	(0.470)
lnpopd	0.189***	0.283***	0.268***	0.102***	0.115*	0.090*	0.053*	0.104*
	(0.000)	(0.000)	(0.000)	(0.000)	0.100	(0.100)	(0.100)	(0.100)
_cons	-20.848	-15.78	-16.72	-11.104	-4.102	-1.710	-2.502	-1.810
	(0.00)	(0.00)	(0.10)	(0.00)	(0.100)	(0.100)	(0.100)	(0.120)
Hansen				30.231				3.790
(p-value)				0.556				(0.891)
AR(1) test				-2.681				-2.000
(p-value)				0.007				(0.045)
AR(2) test				0.340				1.240
(p-value)				0.731				(0.216)
	Central China (iii)				Western China (iv)			
	Pooled OLS	Fixed effect	Random effect	Sys-GMM	Pooled OLS	Fixed effect	Random effect	Sys-GMM
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8

lmpm25								
lnpm25t-1				0.326				0.493
				(0.000)				(0.000)
lnpub	0.187*	0.179**	0.207*	0.273*	0.184*	0.042*	0.034*	0.294*
	(0.100)	(0.090)	(0.100)	(0.100)	(0.100	(0.100)	(0.100)	(0.100)
lnpub2	-0.172*	-0.312*	-0.291*	-0.011*	-0.087*	-0.023*	-0.034*	-0.014*
	(0.100)	(0.100)	(0.100)	(0.100)	(0.100)	(0.100)	(0.100)	(0.100)
lninsec	0.130	0.415**	0.375*	0.427**	1.504**	0.641***	0.731***	0.651***
	(0.210)	(0.051)	(0.100)	(0.041)	(0.011)	(0.002)	(0.002)	(0.061)
lnurbanp	7.172*	10.760**	7.379*	7.288***	13.264***	4.128**	3.251***	7.191***
	(0.100)	(0.073)	(0.100)	(0.009)	(0.002)	(0.075)	(0.002)	(0.000)
lnurbanp2	-0.131*	-1.503**	-1.043**	-1.029***	-1.818***	-0.538*	-0.478*	-0.976***
	(0.100)	(0.072)	(0.087)	(0.007)	(0.007)	(0.100)	(0.100)	(0.000)
lnrgdp	0.786***	-0.065	0.7986	0.590	0.697**	0.315*	0.327*	0.348**
	(0.000)	(0.134)	(0.134)	(0.465)	(0.041)	(0.100)	(0.100)	(0.043)
lnpopd	0.665***	0.217*	0.665***	0.383***	0.126	-0.891**	0.034*	0.052*
	(0.000)	(0.100)	(0.000)	(0.000)	(0.100)	(0.033)	(0.100)	(0.100)
_cons		-16.061	-18.542	-15.583	-30.195***	-15.213*	-15.389*	-15.221***
		(0.100)	(0.017)	(0.000)	(0.003)	(0.100)	(0.100)	0.000
Hansen				-1.891				6.531
(p-value)				(0.059)				(0.988)
AR(1) test				-1.890				-2.171
(p-value)				(0.059)				(0.030)
AR(2) test				-1.010				-1.49

(p-value)	(0.213)	(0.135)

Notes: Variable notations are from Table 6; each variable is in logarithmic form; P-value in parentheses; ***, **, and * indicate rejection of the null hypothesis at 1%, 5% and 10% levels, respectively. POLS: A method of Pooled-OLS; Panel-RE, and Panel-FE: random and fixed effects methods; SYS-GMM: the method of system GMM . Hansen J-test refers to the overidentification test for the restrictions on GMM estimation; the AR (2) test is the Arellano-Bond test for the existence of second-order autocorrelation in first differences.

4.5. Estimations with the PPEB-PHL model for the full sample

Table 7 presents results from the PPEB-PHL model, in which we use the death ratio proxy for the level of public health as the dependent variable. In Columns 1-3, pooled, fixed effects, and random analysis is employed, respecitively, to estimate the PPEB-PHL model in the full sample. As reported, the coefficient on $lnppeb2$ is negative and significant and $lnppeb$ is positive and also significant, indicating that there is an inverted U-shaped relationship between PHL and PPEB in the full simple. The GMM method is then used to estimate this model to address endogeneity problems. The fourth column of the sys-GMM model shows that the value of $lndeath_{t-1}$(0.633) implies that the PHL is corrected by 63.3% each year. We also see that the first and second powers of the PPEB are positive and negative significant, respectively, in which evidence is provided that there exists an inverted U-shaped relationship between PPEB and PHL. We also notice that there is a significantly positive relationship between *lndeath* and $PM_{2.5}$ emissions, and $PM_{2.5}$ emissions contribute to the increase in the death ratio, which is similar to the findings of Gao et al. (2017) and Agarwal et al. (2020); that is, PHL is reduced by $PM_{2.5}$ emissions. The coefficient of *lnrgdp* is negative and significant at the 10% level. This implies that a 1% increase in GDP per capita decreases *lndeath* by 0.056%, which is consistent with the findings of Dong, Zhang, et al. (2019). At the same time, Table 7 also indicates that *lndocp* has a negative and significant impact on *lndeath* at the 10% level. Medical services, in other words, could improve PHL significantly, which further supports the views of Qu and Yan (2015) and Peres et al. (2019).

4.6. Estimations with the PPEB-PHL model for the three regions

In order to further research the regional differences in PPEB, HPG, and PHL, we also examined the eastern (vi), central (vii) and western (viii) regions of China. Results are shown in Table 7. Pooled, fixed effects, and random analysis is employed to estimate the effect of PPEB on PHL for the three regions, respectively. As shown in Table 7, all of the first power and quadratic coefficients of *lnppeb*,are significantly positive and negative, respectively, in the three regions. Furthermore, the GMM method also shows that the first power and quadratic term on *lnppeb* are positive and negative, respectively, which implies that an inverted U-shaped relationship exists between *lndeath* and *lnppeb*. It follows that in the short run, PPEB might have a negative impact on public health—but it could contribute to public health in the long run with an increasing degree of PPEB. We also observe that there is a positive relationship between *lnpm25* and *lndeath*, except for the fixed effects and random effects methods in eastern China, and the fixed effects method in western China. We also find that PHL is more influenced by haze pollution in the central region than in the other two regions. The coefficient of *lnpm25* against *lndeath* is 0.071 at the 5% significance level in the central region, 0.028 at the 1% significance level in the eastern region, 0.018 at the 10% significance level for the whole of China, and 0.007 at the X% significance level in western China, which confirms our important conclusion that haze pollution could seriously damage PHL. Accordingly, the death rate rises by 0.018%, 0.028%, 0.071%, and 0.007%, respectively, in the whole of China and the eastern, central, and western region when haze pollution increases by 1%. The results also show that *lnrgdp* has a significantly negative effect on *lndeath* except for the pooled method in the central region, where the significance level of *lnrgdp* is 0.23. Specifically, at the 1% significance level, a 1% increase in income per capita is associated with a 0.056% decrease in the death rate in the whole of China and at the 10%, 10%, and 5% significance level in the eastern, central, and western regions, respectively. Also, a 1% increase in income per capita is associated with a 0.072%, 0.069% and 0.114% decrease in the death rate in the different regions. In addition, it follows that *lndocp* has a negative effect on *lndeath* at the 1% significance level, except in the western region, and the coefficient for the effect of *lndocp* on *lndeath* rate is ranked in the central region as 0.090, in the western region as 0.060, in the eastern region as 0.054 and in the XXXX as 0.053 using the Sys-GMM method. In addition, the lagged *lndeath* is positively and strongly significant at the 1% level with a coefficient of 0.633, 0.765, 0.517, and 0.521 for the whole of China and the eastern, central, and western regions, respectively.

Table 7

Results for the PPEB-PHL model.

	The whole of China (v)				Eastern China (vi)			
	Pooled OLS	Fixed effect	Random effect	Sys-GMM	Pooled OLS	Fixed effect	Random effect	Sys-GMM
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
	lndeath				lndeath			
lndeatht-1				0.633***				0.765***
				(0.000)				(0.000)
lnpub	0.081***	0.043***	0.045***	0.041***	0.095**	0.066**	0.052*	0.026*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.030)	(0.040)	(0.100)	(0.100)
lnpub2	-0.005***	-0.0024***	-0.0026***	-0.0028**	-0.006**	-0.003**	-0.003*	-0.002*
	(0.000)	(0.000)	(0.000)	(0.050)	(0.020)	(0.080)	(0.100)	(0.10)
lnpm25	0.037***	0.024***	0.028***	0.018*	0.113***	-0.048	-0.013	0.028***
	(0.000)	(0.000)	(0.000)	(0.100)	(0.000)	(0.200)	(0.687)	(0.00)
lnrgdp	-0.073***	-0.049**	-0.048**	-0.056***	-0.027	-0.220***	-0.127***	-0.072*
	(0.000)	(0.090)	(0.080)	(0.000)	(0.200)	(0.000)	(0.000)	(0.10)
lndocp	-0.055***	-0.042**	-0.012**	-0.053*	-0.178***	-0.162***	-0.145***	-0.054*
	(0.000)	(0.090)	(0.090)	(0.100)	(0.000)	(0.000)	(0.000)	(0.10)
cons	2.101	1.709	1.823	0.691	1.794***	0.232*	0.913**	0.453**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.100)	(0.030)	(0.02)
Hansen				-2.891				4.271
(p-value)				(0.021)				(0.473)
AR(1) test				-2.41				-2.21
(p-value)				(0.021)				(0.09)
AR(2) test				1.191				1.030
(p-value)				(0.234)				(0.303)

	Central China (vii)				Western China (viii)			
	Pooled OLS	Fixed effect	Random effect	Sys-GMM	Pooled OLS	Fixed effect	Random effect	Sys-GMM
lndeath	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
lndeatht-1				0.517***				0.521***
				(0.000)				(0.000)
lnppeb	0.045*	0.043*	0.044*	0.044*	0.101***	0.074***	0.073***	0.048***
	(0.100)	(0.100)	(0.100)	(0.100)	(0.000)	(0.000)	(0.000)	(0.000)
lnppeb2	-0.004*	-0.003*	-0.003*	-0.009*	-0.007***	-0.005***	-0.005***	-0.003***
	(0.100)	(0.100)	(0.100)	(0.100)	(0.000)	(0.000)	(0.000)	(0.000)
lnpm25	0.117***	0.081***	0.100***	0.071**	0.013	-0.065	-0.004**	0.007*
	(0.000)	(0.000)	(0.000)	(0.030)	(0.100)	(0.143)	(0.080)	(0.100)
lnrgdp	-0.045	-0.065**	-0.069**	-0.069**	-0.240***	-0.067**	-0.084***	-0.114**
	(0.230)	(0.080)	(0.080)	(0.080)	(0.000)	(0.080)	(0.000)	(0.030)
lndocp	0.112*	0.114***	0.114***	0.090*	0.019	0.049	0.055	0.060
	(0.100)	(0.000)	(0.000)	(0.100)	(0.540)	(0.070)	(0.000)	(0.180)
cons	1.245	1.500	1.500	1.271	3.244	2.176	2.201	1.407
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.010)
Hansen				0.130				3.190
(p-value)				(1.000)				(0.980)
AR(1) test				-2.300				-1.870
(p-value)				(0.021)				(0.060)
AR(2) test				1.460				0.660
(p-value)				(0.143)				(0.510)

Notes: Variable notations are from Table 6; each variable is in logarithmic form; P-values in parentheses; ***, **, and * indicate rejection of the null hypothesis at 1%, 5% and 10% levels, respectively. POLS: A method of Pooled-OLS; Panel-RE and Panel-FE: random and fixed effect methods; SYS-GMM: the method of System GMM. Hansen J-test refers to the overidentification test for the restrictions in GMM estimation; the AR (2) test is the Arellano-Bond test for the existence of second-order autocorrelation in first differences.

4.7. Robustness checks

This section performs robustness checks by replacing $PM_{2.5}$ with sulfur dioxide emissions at the province level and PHL with death rates from cardiovascular and cerebrovascular diseases. Sulfur dioxide is also seen as the main air pollutant and could trigger cardio-cerebrovascular and respiratory disease. The results of robustness test indicate that the coefficients of the level terms *lnpub and lnurbanp are* all positive, while those of quadratic terms are all negative for the PPEB-HPG model, and signs of the other variables are the same as in Table 6 in the full sample and the eastern, central, and western regions. Furthermore, robustness checks also show that the coefficient of the level term *lnpub is* positive, while that of the quadratic term is negative for the PPEB-PHL model, and signs of the other variables are similar to those in Table 7 in the four samples. It is obvious that our empirical results are robust.

5. Discussion

According to the results of Sys-GMM estimation reported in Tables 5 and 6, we can draw the following conclusions. First, for $PM_{2.5}$ in the whole of China, the coefficient of *lnppeb* is estimated to be significantly positive at the 5% level, while the coefficient of its quadratic term is significantly negative at the 1% level. These results indicate that there is an inverted U-shaped relationship between PPEB and haze emissions, which is expected given the subject of this paper. We can calculate that *lnppub* is 8.791 from the equation[1] for the whole of China, while the median of *lnppub* is 8.542. Since 8.791 is more than 8.542, this means that the majority of people are concerned about air quality, and it is important that they continue to be so; PPEB becomes gradually more popular when people take an active part in environmental management (Wang et al., 2016). In addition, China's government has taken many steps to deal with serious haze pollution by replacing

[1] $lnpm25/\partial lnpub = \alpha_{1i} - 2\alpha_{2i} lnppub$

fossil energy, such as coal and oil, with cleaner energy, and cities that depend on a resource economy are being transformed; this also contributes to the reduction of haze pollution (Sun et al., 2019; Wang & Ye, 2017; Zhang & Sun, 2016). The inflection of PPEB has not yet emerged in China; however, it will reach that point soon, if the public and government cooperate to protect the environment. With improvements in the regulation of PPEB and the emphasis on self-health, PPEB will ultimately have radically positive effects on haze pollution.

For the eastern, central, and western regions, an inverted U-shaped relationship is confirmed between PPEB and haze pollution, and the coefficient of PPEB in the eastern region is more significant than in the other two regions. From the equation[2], we can calculate that *lnppeb* is 13.671 more than the median of 9.112 in the eastern region, 12.417 more than the median of 8.656 in the central region, and 10.513 more than the median of 7.938 in the western region, which implies that the inflection point of PPEB has still not been reached. This probably explains why there is a higher living standard, higher environmental awareness, and greater concern about self-health in the eastern region than in the other two regions. Also, there is more rapid development in eastern tertiary industries than in the other two regions, so the extent to which the public attaches importance to the management of environmental protection will easily have an impact on the reduction of environmental pollution. In particular, haze pollution will decrease when the PPEB rises increasingly and reaches a threshold value, although haze pollution might initially increase until the scale of PPEB gets larger.

Incidentally, there an inverted U-shaped relationship exists between urbanization and haze pollution; the coefficient of *lnurbanp* is significantly positive, while that of its quadratic term is significantly negative at the 1% significance level for the full sample, which is consistent with some recent studies (Wang et al., 2018). According to the estimation results shown in Table 6, the levels of urbanization that correspond to the turning points of the curve for haze pollution could be calculated for the whole country; namely, according to the equation[3], $lnurbanp = 3.495$, which is less than the median of 3.844 in Table 1. It also follows that the reciprocal U kink of urbanization with respect to haze pollution has just arrived in China. Although a growing population's vehicles and fossil energy consumption would generate a lot of soot dust, smoke, $PM_{2.5}$, and so on, given the decades of an increasing pace of urbanization and industrialization, China's governments have

---

[2] $\partial lnpm25/\partial lnpub = \alpha_{1i} - 2\alpha_{2i} lnppub$

[3] $\frac{\partial lnpm25_{it}}{\partial lnurbanp_{it}} = \alpha_6 + \alpha_7 lnurbanp_{it}$

implemented a wide range of strong measures that are mainly used to restrict the emission of pollutants—for example, transititioning from resource economics to the new energy economics, improving cycling equipment, strengthening and innovative power. Similarly, there is also a confirmed inverted U-shaped relationship between haze pollution and urbanization at the 10% and 1% levels of significance for central and western China, respectively, but not for eastern China. This is probably one reason China's eastern region is the most developed in its economy, and residents' incomes are much higher than in other regions. This allows their cities to develop quicker, and there is a more highly developed culture in the eastern region. As a result, the extent to which their cities develop rapidly has surpassed the inflection point. This result strongly supports the viewpoints of Wang et al. (2018) and Behera and Dash (2017). In addition, more PPEB can accelerate the pace of eastern regional urbanization, because people have been immigrating from the central and western regions to the eastern region, which means that the eastern region will consume more energy and lead to more environmental pollutants. Meanwhile, people can spend more on natural gas, electrical power, and other renewable energy sources for household energy use in daily life than when they lived in rural areas, which substantially reduces the proportion of fossil energy of total energy consumption(Mrabet et al., 2019; Salim et al., 2019; Yang et al., 2016). For the central and western regions, although they continue to progress in that many companies have been transforming from energy-intensive industries to service ones with the encouragement of local governments, the public's environmental awareness is not as high as in the eastern region. Enterprises located in the western region don't have the more advanced technical skills for fossil energy, whereby a lot of fossil energy hasn't been used more efficiently; this results in pollutant emissions to a certain degree(C. Zhang et al., 2019; Zhu et al., 2019). Undoubtedly, more and more people place an emphasis on their environment as it related to a higher standard of living, and PPEB has become an essential aspect of environmental management. Thus, to a certain degree, PPEB will lead to the reduction of haze pollution.

The effect of fossil energy consumption on haze pollution is significantly positive in the full sample and the eastern, central, and western regions, and this paper's results are as expected—similar to the outcomes of Hou et al., 2019; Jiang et al., 2020; and Qu and Yan, 2015. The uneven structure of energy consumption could significantly differentiate haze pollution in each region of China. In addition, there are several possible reasons for the distinctive difference between GDP per capita and haze pollution in each region. First, local economic growth has mainly been increased by industries that use large amounts of fossil energy, because there are fewer tertiary industries in the western region (Jiang et al., 2020; Li et al., 2019). Second, there are more service industries and more highly technical industries in the eastern and central regions, which do not contribute to environmental pollution such as haze(Liu et al., 2019). Third, haze pollution could have spillover effects adjacent to the region, and there is no significance level in the eastern and central regions that can't offset by the significance level in the western region. These reasons for the positive effects of *popd* on haze pollution can summed up as follows. (1) The population scale will lead to the amount of energy consumption and further contribute to more haze pollution with the faster urbanization and industrialization of China (Chen & Chen, 2019). (2) The rapid population growth causes a series of social problems, such as building shortages and insufficient land, which means less vegetation; thus, less haze pollution is absorbed (Weber & Sciubba, 2019).

For the PPEB-PHL model, the U-shaped relationship between PPEB and PHL in the full sample and each region; these are important and pioneering findings; previous studies have not examined the effects of PPEB on PHL using econometric methods. Prior studies have only described their relationships; for example, G. Zhang et al. (2019) and Qu and Yan (2017). Moreover, the higher significance level for the coefficient of PPEB to PHL is present in the whole country and the western region compared with the eastern and central regions. This might be due to two reasons. First, PPEB, by itself, to some extent could help people become aware of the environmental issues involved in public health improvement. People in China are becoming more concerned about environmental pollution, and especially haze pollution as a trigger for cardio-cerebrovascular diseases. The influence of PPEB on environmental issues may not emerge for some length of time because this is a longer process; also, the strength of the PPEB will not hinder environmental pollutants at first or reduce the death rate. This shows the positive relationship between the death rate and PPEB—in other words, there exists a negative relationship between HPG and PPEB. However, PPEB will broadly contribute to environmental improvement, and thus also enhance PHL with the horizon of PPEB largely; in the end, PPEB will have a substantial positive impact on PHL. Second, for the western region, environmental pollution is more serious than in the eastern and central regions, and the economic level is also lower than in those two regions. Undoubtedly, the effect of PPEB on pollution in the western region is more sensitive than in the eastern and central regions. Additionally, there is a large difference in educational level and the degree of environmental culture and awareness among three regions, and attention to PPEB is still not enough overall. Consequently, this demonstrates that the relationship between PPEB and HPG is significantly negative for the whole country at the beginning stage. With more attention to public health and environmental issues, PPEB will contribute to public health improvement when it reaches a certain degree.

For $PM_{2.5}$, the coefficient is significantly positive in the full sample and each subsample. This result is expected, given the paper's objective, which is similar to several previous studies (Gao et al., 2017; Qu & Yan, 2015). $PM_{2.5}$ can damage the human respiratory and cardiovascular systems, because it can enter the lungs and blood via the respiratory tract, and can cause death (Li et al., 2016; Yuan et al., 2018). This is especially true in the central region, which is famous for producing energy from coal. The impact of income on the death rate is significantly negative in each region, and the increase in life expectancy could contribute to PHL to a degree, which is confirmed by previous studies (Greco et al., 2016; Qu & Yan, 2015). Also, living conditions in the western region are more arduous than in the other regions, and more educated people are not volunteering to settle there. To a degree, this phenomenon gives rise to the poor level of productivity and more haze pollution; this is one reason the scale of physicians has a statistically insignificant effect on PHL.

6. Conclusions and policy implications

Since the early 1980s, China has witnessed substantial progress in urbanization and industrialization and consumed more fossil energy with the fast development of the economy. However, it has also suffered from severe environmental deterioration, and especially haze pollution, which is a trigger for respiratory, cardiovascular, neurological, etc., disease. There is an extensive literature that finds that PPEB has an inhibiting effect on haze pollution caused by fossil energy consumption and thus improves public health; however, previous quantitative studies that examine the influencing factors of haze pollution and public health do not incorporate PPEB.

We argue that PPEB is indeed an essential factor in haze governance and PHL, and are the first to empirically examine the nonlinear relationship between PPEB and haze pollution and PPEB and PHL with other relevant variables using a panel dataset that consists of 31 provinces in mainland China from 2000 to 2017. We employ a panel unit root test, cointegration test, pool OLS, fixed effects, random effects, and Sys-GMM, which have the advantage of overcoming endogenous problems caused by the correlation between explanatory variables and error terms. We further split the full sample into eastern, central, and western regions in order to reexamine and confirm results for the whole country. Our main conclusions are as follows.

With respect to the PPEB-HPG model, (1) there exists an inverted U-shaped relationship between PPEB and HPG, which shows that PPEB, to a large extent, could contribute to the governance of haze pollution in China and each region. The different significance levels of the PPEB coefficient relevant to HPG are also evident in the full sample and subsamples. For example, the most significant impact of PPEB on the whole country and the eastern region was evidenced by the greater levels of PPEB than in the central and western regions. (2) The extent of PPEB has not increased, and it still has not reached an inflection point, which demonstrates the different features of the whole country and each region. (3) We also find an inverted U-shaped relationships between urbanization and HPG, except in the eastern region. (4) Fossil energy has a positive effect on HPG except in the eastern region, but appears to have different significance levels because of the unbalanced structure of energy in China. (5) There is evidence that people's income per capita and HPG have a positive relationship, except in the eastern and central regions, which implies that environmental pollution will not absolutely deteriorate with economic development. (6) Population density could cause haze pollution to increase in the whole country and each region.

With respect to the PPEB-PHL model: (1) the results show that PPEB also has an inverted U-shaped relationship with the death rate; namely, the U-shaped relationship with the PHL, but with different significance levels of PPEB with respect to the death rate in the whole country and each region. (2) Haze pollution is a greater threat to public health improvement in the whole of China and the central region. (3) The increase in income per capita will promote the improvement of public health and reduce death rates. (4) To some extent, medical services could improve public health and inhibit death rates.

Drawing on the above findings, we can make some policy recommendations for the whole country and each region that implement HPG and improve PHL. First, as the primary obstacle to inhibiting resource economic transformation, the lack of public awareness about environmental protection causes serious air pollution except for fossil energy. Thus, passive and forced PPEB is not advisable in the urbanization process, even with restricted governmental regulation. Instead, the implementation of PPEB is given priority to local areas and communities, and this is a good example for the whole society of advertising for environmental protection.

Specifically, for the eastern region where people have a relatively higher income, the emphasis on environmental culture is part of daily life—for example, saving energy, using green products, separating garbage, and so on. It is necessary that the public advertise the importance of PPEB, and make people aware of the nonnegligible effects of PPEB on HPG and PHL. People should be told how haze pollution affects public health and how it triggers illness. Policymakers should clearly understand the essential role of PPEB in environmental management in order to enact efficient environmental laws, and motivate efficient PPEB. At the same time, the government should improve the mechanism of information disclosure so that the public is informed on a timely basis environmental quality. It is difficult for the public to understand information about corporate environmental behavior if an institutional system of information disclosure is not established, if this is accomplished, however, PPEB would have a real effect on environmental governance. In addition, with reference to European countries' experience with PPEB, it is necessary to make the public proactive participants before, during, and after the event, and for policymakers to make better use of PPEB to improve haze pollution and PHL from the legal regulation.

For the central and western regions, on the one hand, governments should make great effort to emphasize the positive effects of PPEB on environmental improvement and foster public awareness of environmental protection. On the other hand, governments should encourage the public to establish environmental groups—and even environmental children's organizations to highlight PPEB concepts. More importantly, governments should attach importance to publicizing the threat of haze pollution to PHL, which acts as a trigger for cardiovascular and cerebrovascular diseases, and especially for the elderly and children. As shown by our results, medical services have a positive effect on PHL; therefore, it is urgent that medical workers take an active part in the governance of haze pollution to enlargie the scale of PPEB and serve as good examples for the general public. Policymakers should consider incorporating medical workers into groups within PPEB. Also, attention to PPEB should be fostered during urbanization in people's daily lives to encourage the public to drive green—for example, the electric taxis in Shanxi province should be popularized throughout the whole country.

Governments should make PPEB indispensable in supervising enterprises' emissions. On the one hand, policymakers encourage enterprises themselves to decrease pollution via energy technological innovation to improve air quality. On the other hand, governments should give priority to the general public in environmental supervision, and make the role of PPEB more efficient. Hence, adding investment in PPEB and renewable energy is expected to contribute significantly to abating haze pollution instead of aggravating it and reducing PHL Only then will a combination of PPEB and the transformation of energy reach its potential; haze pollution could be completely reduced, and in turn improve PHL. Short-term policies, such as subsidizing the cost of PPEB, and long-term policies, such as guiding and encouraging the public to join in environmental regulation, should be made as complete as possible. It is imperative that differentiated policies of PPEB be implemented in different regions due to the variety of environmental knowledge, culture, and awareness.

For remote villages, the government should publicize the role of PPEB in environmental governance by TV advertisements and posters and encourage the public to learn about the hazards of haze pollution to PHL, such as respiratory and cerebrovascular diseases. In order to improve rural eco-environmental quality and quicken the step of rural urbanization, it is important to strengthen rural residents' environmental awareness and deeply root PPEB in the village. In accelerating the transformation of fossil energy for cooking and heating, it might be wise to develop methane energy, which not only makes efficient use of animal dung but also reduces air pollution. Hence, the government should encourage residents to invest more in methane energy.

Although this research obtains important results that previously unknown and provides beneficial findings and implications for governments, it is necessary to highlight the study's limitations. First, due to data availability, the measure of PPEB only includes people's environmental letters; other environmental behavior is not incorporated, which could be improved in future work. Second, many other factors come into play for the effects of HPG, such as international cooperation; this aspect should be considered in future researches. Last, as significant differences exist across countries, such as the degree of participation in and cultural education about PPEB, our findings may not apply to other countries. More quantitative analysis is encouraged to reexamine the role of PPEB in the field of public participation in environmental protection and in other countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank the financial support provided by the National Natural Science Foundation of China (71874103) and the Supported by the fund for the Shanxi "1331 Project" Key Innovative Research Team(1331KIRT).

References

Agarwal, S., Sing, T.F., & Yang, Y., 2020. The impact of transboundary haze pollution on household utilities consumption. Energy Economics, 85, 104-591.

Andrade, L.O.M., Pellegrini Filho, A., Solar, O., Rígoli, F., Salazar, L.M., Serrate, P.C.-F., . . . Atun, R., 2015. Social determinants of health, universal health coverage, and sustainable development: case studies from Latin American countries. The Lancet, 385(9975), 1343-1351.

Arellano, M., & Bond, S., 1991. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. The review of economic studies, 58(2), 277-297. doi:10.2307/2297968

Behera, S.R., & Dash, D.P., 2017. The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region. Renewable and Sustainable Energy Reviews, 70, 96-106. doi:https://doi.org/10.1016/j.rser.2016.11.201

Bhattacharya, M., Churchill, S.A., & Paramati, S.R., 2017. The dynamic impact of renewable energy and institutions on economic output and CO2 emissions across regions. Renewable Energy, 111, 157-167.

Bilgili, F., Koçak, E., & Bulut, Ü., 2016. The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. Renewable Sustainable Energy Reviews, 54, 838-845.

Blundell, R., & Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics, 87(1), 115-143. doi:https://doi.org/10.1016/S0304-4076(98)00009-8

Brombal, D., Moriggi, A., & Marcomini, A., 2017. Evaluating public participation in Chinese EIA. An integrated Public Participation Index and its application to the case of the New Beijing Airport. Environmental Impact Assessment Review, 62, 49-60.

Cao, C., Lee, X., Liu, S., Schultz, N., Xiao, W., Zhang, M., & Zhao, L., 2016. Urban heat islands in China enhanced by haze pollution. Nature Communications, 7(1), 1-7.

Cao, Z., Wang, M., Chen, Q., Zhang, Y., Dong, W., Yang, T., . . . Xi, B., 2018. Preliminary assessment on exposure of four typical populations to potentially toxic metals by means of skin wipes under the influence of haze pollution. Science of The Total Environment, 613, 886-893.

Cesari, M., Prince, M., Thiyagarajan, J.A., De Carvalho, I.A., Bernabei, R., Chan, P., . . . Ong, P., 2016. Frailty: an emerging public health priority. Journal of the American Medical Directors Association, 17(3), 188-192.

Chen, H., & Chen, W., 2019. Potential impacts of coal substitution policy on regional air pollutants and carbon emission reductions for China's building sector during the 13th Five-Year Plan period. Energy Policy, 131, 281-294.

Chen, M., Qian, X., & Zhang, L., 2015. Public participation in environmental management in China: status quo and mode innovation. Environmental management, 55(3), 523-535.

Chen, R., Hu, B., Liu, Y., Xu, J., Yang, G., Xu, D., & Chen, C., 2016. Beyond PM2. 5: the role of ultrafine particles on adverse health effects of air pollution. Biochimica et Biophysica Acta -General Subjects, 1860(12), 2844-2855.

Chen, X., Shao, S., Tian, Z., Xie, Z., & Yin, P.J.J.o.c.p., 2017. Impacts of air pollution and its spatial spillover effect on public health based on China's big data sample. 142, 915-925.

Chen, Y., He, G., Chen, B., Wang, S., Ju, G., & Ge, T., 2020. The association between PM2. 5 exposure and suicidal ideation: a prefectural panel study. Bmc Public Health, 20(1), 1-10.

Cheng, Z., Li, L., & Liu, J., 2017. Identifying the spatial effects and driving factors of urban PM2. 5 pollution in China. Ecological Indicators, 82, 61-75.

Choi, I., 2001. Unit root tests for panel data. Journal of international money and Finance, 20(2), 249-272.

Dahal, S., Mizumoto, K., Bolin, B., Viboud, C., & Chowell, G., 2018. Natality decline and spatial variation in excess death rates during the 1918–1920 influenza pandemic in Arizona, United States. Am J Epidemiol, 187(12), 2577-2584.

Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. Ecological Economics, 49(4), 431-455.

Dong, F., Yu, B., & Pan, Y., 2019. Examining the synergistic effect of CO2 emissions on PM2. 5 emissions reduction: Evidence from China. Journal of Cleaner Production, 223, 759-771.

Dong, F., Zhang, S., Long, R., Zhang, X., & Sun, Z., 2019. Determinants of haze pollution: An analysis from the perspective of spatiotemporal heterogeneity. Journal of Cleaner Production, 222, 768-783.

Drazkiewicz, A., Challies, E., & Newig, J., 2015. Public participation and local environmental planning: Testing factors influencing decision quality and implementation in four case studies from Germany. Land Use Policy, 46, 211-222.

Dunlap, R.E., & Mertig, A.G., 2014. Trends in public opinion toward environmental issues: 1965–1990. American environmentalism, 101-128.

Eckelman, M.J., & Sherman, J., 2016. Environmental impacts of the US health care system and effects on public health. PLoS One, 11(6), 0157-0174.

Evans, G.W., & Kantrowitz, E., 2002. Socioeconomic status and health: the potential role of environmental risk exposure. Annual review of public health, 23(1), 303-331.

Ford, E.S., & Capewell, S., 2011. Proportion of the decline in cardiovascular mortality disease due to prevention versus treatment: public health versus clinical care. Annual review of public health, 32, 5-22.

Fu, J., & Geng, Y., 2019. Public participation, regulatory compliance and green development in China based on provincial panel data. Journal of Cleaner Production, 230, 1344-1353.

Gao, J., Woodward, A., Vardoulakis, S., Kovats, S., Wilkinson, P., Li, L., . . . Cao, L., 2017. Haze, public health and mitigation measures in China: A review of the current evidence for further policy response. Science of The Total Environment, 578, 148-157.

Gill, A.R., Viswanathan, K.K., & Hassan, S., 2018. The Environmental Kuznets Curve (EKC) and the environmental problem of the day. Renewable and Sustainable Energy Reviews, 81, 1636-1642.

Glucker, A.N., Driessen, P.P., Kolhoff, A., & Runhaar, H., 2013. Public participation in environmental impact assessment: why, who and how? Environmental Impact Assessment Review, 43, 104-111.

Greco, G., Lorgelly, P., & Yamabhai, I., 2016. Outcomes in economic evaluations of public health interventions in low-and central-income countries: health, capabilities and subjective wellbeing. Health economics, 25, 83-94.

Grossman, M., 1972. On the concept of health capital and the demand for health. Journal of Political economy, 80(2), 223-255.

Guarnieri, M., & Balmes, J., 2014. Outdoor air pollution and asthma. The Lancet, 383(9928), 1581-1592.

Héroux, M.E., Anderson, H.R., Atkinson, R., Brunekreef, B., Cohen, A., Forastiere, F., . . . Krzyzanowski, M., 2015. Quantifying the health impacts of ambient air pollutants: recommendations of a WHO/Europe project. International journal of public health, 60(5), 619-627.

Ho, A.F.W., 2018. The Relationship Between Ambient Air Pollution and Acute Ischemic Stroke: A Time-Stratified Case-Crossover Study in a City-State With

Seasonal Exposure to the Southeast Asian Haze Problem." Annals of Emergency Medicine. 72(5), 591-601.

Hou, J., Wang, J., Chen, J., & He, F., 2019. Does urban haze pollution inversely drive down the energy intensity? A perspective from environmental regulation. Sustainable Development, 28, 343-351.

Im, K.S., Pesaran, M.H., & Shin, Y., 2003. Testing for unit roots in heterogeneous panels. Journal of Econometrics, 115(1), 53-74.

Islam, M.R., & McGillivray, M., 2020. Wealth inequality, governance and economic growth. Economic Modelling, 88, 1-13.

Ji, X., Yao, Y., & Long, X., 2018a. What causes PM2.5 pollution? Cross-economy empirical analysis from socioeconomic perspective. Energy Policy.

Ji, X., Yao, Y., & Long, X., 2018b. What causes PM2. 5 pollution? Cross-economy empirical analysis from socioeconomic perspective. Energy Policy, 119, 458-472.

Jia, S., Liu, X., & Yan, G., 2019. Effect of APCF policy on the haze pollution in China: A system dynamics approach. Energy Policy, 125, 33-44.

Jiang, N., Fan, W., Xie, X., Guo, F., Li, E., Zhao, S., & Xu, Y., 2020. Energy, economic, environmental and engineering quantity optimization of industrial energy recovery network. Journal of Cleaner Production, 120-157.

Kan, H., Chen, R., & Tong, S., 2012. Ambient air pollution, climate change, and population health in China. Environment international, 42, 10-19.

Kao, C., 1999. Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90(1), 1-44.

Keček, D., Mikulić, D., & Lovrinčević, Ž., 2019. Deployment of renewable energy: Economic effects on the Croatian economy. Energy Policy, 126, 402-410.

Landrigan, P.J., Fuller, R., Acosta, N.J., Adeyi, O., Arnold, R., Baldé, A.B., . . . Breysse, P.N., 2018. The Lancet Commission on pollution and health. The Lancet, 391(10119), 462-512.

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., & Pozzer, A., 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525(7569), 367-371.

Levin, A., Lin, C.-F., & Chu, C.-S.J., 2002. Unit root tests in panel data: asymptotic and finite-sample properties. Journal of Econometrics, 108(1), 1-24.

Li, L., Lei, Y., Pan, D., Yu, C., & Si, C., 2016. Economic evaluation of the air pollution effect on public health in China's 74 cities. SpringerPlus, 5(1), 402.

Li, L., Liu, X., Ge, J., Chu, X., & Wang, J., 2019. Regional differences in spatial spillover and hysteresis effects: A theoretical and empirical study of environmental regulations on haze pollution in China. Journal of Cleaner Production, 230, 1096-1110.

Li, L., Xia, X., Chen, B., & Sun, L., 2018. Public participation in achieving sustainable development goals in China: Evidence from the practice of air pollution control. Journal of Cleaner Production, 201, 499-506.

Li, z.h., 2017. The Impact of Public Participation on Local Government's Environmental Governance—— An Analysis of Provincial Data 2003-2013. Chinese

Public Administration(8), 102-108.

Liao, X., 2018. Public appeal, environmental regulation and green investment: Evidence from China. Energy Policy, 119, 554-562.

Liu, H., Fang, C., Zhang, X., Wang, Z., Bao, C., & Li, F., 2017. The effect of natural and anthropogenic factors on haze pollution in Chinese cities: A spatial econometrics approach. Journal of Cleaner Production, 165, 323-333.

Liu, L., Ding, D., & He, J., 2019. Fiscal decentralization, economic growth, and haze pollution decoupling effects: A simple model and evidence from China. Computational Economics, 54(4), 1423-1441.

Maddala, G.S., & Wu, S., 1999. A comparative study of unit root tests with panel data and a new simple test. Oxford Bulletin of Economics and statistics, 61(S1), 631-652.

McKenzie, L.M., Witter, R.Z., Newman, L.S., & Adgate, J., 2012. Human health risk assessment of air emissions from development of unconventional natural gas resources. Science of The Total Environment, 424, 79-87.

McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., Bonney, R., Brown, H., Cook-Patton, S.C., . . . Soukup, M.A., 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. Biological Conservation, 208, 15-28. doi:https://doi.org/10.1016/j.biocon.2016.05.015

Mrabet, Z., Alsamara, M., Saleh, A.S., & Anwar, S., 2019. Urbanization and non-renewable energy demand: A comparison of developed and emerging countries. Energy, 170, 832-839.

Nasrollahi, Z., Hashemi, M.-s., Bameri, S., & Taghvaee, V.M., 2018. Environmental pollution, economic growth, population, industrialization, and technology in weak and strong sustainability: using STIRPAT model. Environment, Development and Sustainability, 1-18.

Oreggioni, G., Luberti, M., & Tassou, S., 2019. Agricultural greenhouse CO2 utilization in anaerobic-digestion-based biomethane production plants: A techno-economic and environmental assessment and comparison with CO2 geological storage. Applied Energy, 242, 1753-1766.

Özokcu, S., & Özdemir, Ö., 2017. Economic growth, energy, and environmental Kuznets curve. Renewable and Sustainable Energy Reviews, 72, 639-647.

Pedroni, P., 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bulletin of Economics and statistics, 61(S1), 653-670.

Pedroni, P., 2001. Purchasing power parity tests in cointegrated panels. Review of Economics and statistics, 83(4), 727-731.

Pedroni, P., 2004. Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric theory, 20(3), 597-625.

Peres, M.A., Macpherson, L.M., Weyant, R.J., Daly, B., Venturelli, R., Mathur, M.R., . . . Kearns, C., 2019. Oral diseases: a global public health challenge. The Lancet, 394(10194), 249-260.

Qu, W.H., Qu, G.H., Zhang, X.D., & Yan, Z.J., 2018. Effects of private car ownership, economic growth and medical services on healthcare expenditure in China: a dynamic panel data analysis. Natural Hazards, 93(1), 167-188.

Qu, W.H., Xu, L., Qu, G.H., Yan, Z.J., & Wang, J.X., 2017. The impact of energy consumption on environment and public health in China. Natural Hazards, 87(2), 675-697. doi:10.1007/s11069-017-2787-5

Qu, W.h., & Yan, Z.j., 2014. Impact of energy consumption on environment and public health:empirical evidence from Shanxi province. Journal of Beijing Institute of Technology(Social Sciences Edition), 16(4), 33-41.

Qu, W.H., & Yan, Z.J., 2015. The Influence of Evironmental Pollution, Economic Growth and Healthcare Services to Public Health Based on China's Provincial Panel Data. Chinese Jounal of Management Science, 23(7), 166-176 (in Chinses).

Qu, W.H., & Yan, Z.J., 2017. Evolutionary analysis of incentive mechanisms for enterprises， governments，and the public to achieve environmental health improvements. CAAI Transactions on Intelligent Systems, 12(2), 37-43(in Chinese).

Reed, M.S.J.B.c., 2008. Stakeholder participation for environmental management: a literature review. 141(10), 2417-2431.

Rega, C., & Baldizzone, G., 2015. Public participation in Strategic Environmental Assessment: A practitioners' perspective. Environmental Impact Assessment Review, 50, 105-115.

Roodman, D., 2009. How to do xtabond2: An introduction to difference and system GMM in Stata. The stata journal, 9(1), 86-136.

Rowe, G., Frewer, L., & values, h., 2000. Public participation methods: a framework for evaluation. Science, technology,, 25(1), 3-29.

Ru, X., Qin, H., & Wang, S., 2019. Young people's behaviour intentions towards reducing PM2.5 in China: Extending the theory of planned behaviour. Resources Conservation and Recycling, 141, 99-108.

Salim, R., Rafiq, S., Shafiei, S., & Yao, Y., 2019. Does urbanization increase pollutant emission and energy intensity? evidence from some Asian developing economies. Applied economics, 51(36), 4008-4024.

Seaton, A., Godden, D., MacNee, W., & Donaldson, K.J.T.l., 1995. Particulate air pollution and acute health effects. 345(8943), 176-178.

Shahbaz, M., Chaudhary, A., & Ozturk, I., 2017. Does urbanization cause increasing energy demand in Pakistan? Empirical evidence from STIRPAT model. Energy, 122, 83-93.

Shahbaz, M., Loganathan, N., Muzaffar, A.T., Ahmed, K., & Jabran, M.A., 2016. How urbanization affects CO2 emissions in Malaysia? The application of

STIRPAT model. Renewable and Sustainable Energy Reviews, 57, 83-93.

Sharma, S.S.J.A.E., 2011. Determinants of carbon dioxide emissions: Empirical evidence from 69 countries. 88(1), 376-382.

Shen, D., Xia, M., Zhang, Q., Elahi, E., Zhou, Y., & Zhang, H., 2019. The impact of public appeals on the performance of environmental governance in China: A perspective of provincial panel data. Journal of Cleaner Production, 231, 290-296.

Shi, G.-M., Bi, J., & Wang, J.-N., 2010. Chinese regional industrial energy efficiency evaluation based on a DEA model of fixing non-energy inputs. Energy Policy, 38(10), 6172-6179. doi:https://doi.org/10.1016/j.enpol.2010.06.003

Song, Y., Zhao, C., & Zhang, M., 2019. Does haze pollution promote the consumption of energy-saving appliances in China? An empirical study based on norm activation model. Resources, Conservation and Recycling, 145, 220-229.

Sun, C., Ding, D., Fang, X., Zhang, H., & Li, J., 2019. How do fossil energy prices affect the stock prices of new energy companies? Evidence from Divisia energy price index in China's market. Energy, 169, 637-645.

Tong, Z., Chen, Y., Malkawi, A., Liu, Z., & Freeman, R.B.J.A.e., 2016. Energy saving potential of natural ventilation in China: The impact of ambient air pollution. 179, 660-668.

Uddin, M.A., Ali, M.H., & Masih, M., 2017. Political stability and growth: An application of dynamic GMM and quantile regression. Economic Modelling, 64, 610-625.

Wang, X., Tian, G., Yang, D., Zhang, W., Lu, D., & Liu, Z., 2018. Responses of PM2. 5 pollution to urbanization in China. Energy Policy, 123, 602-610.

Wang, Y., Sun, M., Yang, X., & Yuan, X., 2016. Public awareness and willingness to pay for tackling smog pollution in China: a case study. Journal of Cleaner Production, 112, 1627-1634.

Wang, Z.-X., & Ye, D.-J., 2017. Forecasting Chinese carbon emissions from fossil energy consumption using non-linear grey multivariable models. Journal of Cleaner Production, 142, 600-612.

Weber, H., & Sciubba, J.D., 2019. The effect of population growth on the environment: Evidence from European regions. European Journal of Population, 35(2), 379-402.

Wei, J., & Zhang, Y.-J., 2020. Exploring a strategy for tall office buildings based on thermal energy consumption from industrialized perspective: An empirical study in China. Journal of Cleaner Production, 120-497.

Wu, Dai, H., Geng, Y., Xie, Y., Masui, T., Liu, Z., & Qian, Y., 2017. Economic impacts from PM2. 5 pollution-related health effects: a case study in Shanghai. Environmental science & technology, 51(9), 5035-5042.

Wu, J., Xu, M., & Zhang, P., 2018. The impacts of governmental performance assessment policy and citizen participation on improving environmental performance across Chinese provinces. Journal of Cleaner Production, 184, 227-238.

Xu, Z., Shan, J., Li, J., & Zhang, W., 2020. Extending the theory of planned behavior to predict public participation behavior in air pollution control: Beijing, China. Journal of Environmental Planning and Management, 63(4), 669-688.

Yang, J., Zhang, W., & Zhang, Z., 2016. Impacts of urbanization on renewable energy consumption in China. Journal of Cleaner Production, 114, 443-451.

Yi, M., Wang, Y., Sheng, M., Sharp, B., & Zhang, Y., 2020. Effects of heterogeneous technological progress on haze pollution: Evidence from China. Ecological Economics, 169, 106533.

York, R., Rosa, E.A., & Dietz, T., 2003. STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological Economics, 46(3), 351-365.

Yuan, M., Huang, Y., Shen, H., & Li, T., 2018. Effects of urban form on haze pollution in China: Spatial regression analysis based on PM2. 5 remote sensing data. Applied geography, 98, 215-223.

Yue, X., Unger, N., Harper, K., Xia, X., Liao, H., Zhu, T., . . . Li, J., 2017. Ozone and haze pollution weakens net primary productivity in China. Atmospheric Chemistry and Physics, 6073-6089.

Zhang, C., Zhou, B., & Wang, Q., 2019. Effect of China's western development strategy on carbon intensity. Journal of Cleaner Production, 215, 1170-1179.

Zhang, G., Deng, N., Mou, H., Zhang, Z.G., & Chen, X., 2019. The impact of the policy and behavior of public participation on environmental governance performance: Empirical analysis based on provincial panel data in China. Energy Policy, 129, 1347-1354.

Zhang, S., Worrell, E., & Crijns-Graus, W.J.A.E., 2015. Evaluating co-benefits of energy efficiency and air pollution abatement in China’s cement industry. 147, 192-213.

Zhang, X.J., Zhao, k., & Lou, C.w., 2014. The Influence Mechanism of Public Particiaption on Environmental quality. Urban Problems(4), 84-90.

Zhang, Y.-J., & Sun, Y.-F., 2016. The dynamic volatility spillover between European carbon trading market and fossil energy market. Journal of Cleaner Production, 112, 2654-2663.

Zhu, L., Wang, Y., Shang, P., Qi, L., Yang, G., & Wang, Y., 2019. Improvement path, the improvement potential and the dynamic evolution of regional energy efficiency in China: Based on an improved nonradial multidirectional efficiency analysis. Energy Policy, 133, 110883.