SMOG POLLUTION, PUBLIC HEALTH AND FAMILY FINANCIAL BURDEN: EVIDENCE FROM CHINA

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Abstract. Using Chinese provincial data from 2008 to 2022, this study constructs a spatial panel data model to empirically analyze the impact of smog pollution on family financial burden, and public health's moderating effect on this relationship and the regional heterogeneity of this moderating effect. The results show that after controlling the economic development, human capital, environmental regulation, and other provincial variables, smog pollution significantly positively (negatively) affects family financial burden (public health). Furthermore, public health partially mediates the relationship between smog pollution and family financial burden. Thus, the impact of smog pollution on family financial burden can be partially realized through public health. Regionally, the impact of smog pollution on family financial burden in central and western China is higher than that in eastern China.
Keywords: *healthy China, labor productivity, mediating effect, intermediary effect, regional heterogeneity*

Introduction

The impact of the health effects of smog pollution on family financial burden is a systematic process. At present, the situation of smog pollution in China is severe, and the health of residents is seriously threatened. Reducing the family financial burden caused by smog pollution is an integral part of building a healthy China. Smog weather affects a wide range of areas, lasts for a long time, and causes high pollution levels. China has stepped up the implementation of emission reduction policies to control smog weather and "solidly promote common prosperity", as was proposed in the report of the 20th National Congress of the Communist Party of China. With these efforts, the relationship between smog pollution, public health, and family financial burden in China has attracted widespread attention. Specifically, the emissions of SOx, smoke, and other harmful substances are important factors in the formation of smog, causing serious environmental pollution and public health problems (Afshin et al., 2019, Aloi and Tournemaine, 2011). According to the Lancet's "Global Burden of Disease Report 2019," China's PM (Particulate Matter) 2.5 caused 1.2 million early deaths and 25 million disability-adjusted life-year losses in 2019. However, the link between smog pollution and public health is not unidirectional. Environmental pollution affects core factors of production related to income, such as healthy human capital, labor productivity, and labor hours. For example, Zivin and Neidell (2012), Chang et al. (2019) believe that air pollution can reduce workers' environmental expectations, inhibit labor payment willingness, and reduce daily output and labor productivity.

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Hanna and Oliva (2015) argue that air pollution reduces labor supply. Thus, smog pollution leads to relative changes in the healthy human capital investment and stock of Chinese families, and thus, affects the financial burden of households. Considering this perspective, we empirically examine the impact of smog pollution on family financial burden in China, and the mediating role of public health in this relationship. China is facing a new development stage in which the economy is turning towards a new normal, the industrial structure is upgrading, and the population aging continues to intensify the transition from population dividends to health dividends. Based on this, this article focuses on how the family financial burden changes when the workers is affected by the impact of smog pollution on public health. This is in line with China's national strategy and has important practical significance. With collecting the Chinese provincial panel data from 2008 to 2022, we build a macro health production function using the Generalized Method of Moments (GMM)) method with bidirectional fixed effects and dynamic panel. The remaining sections of this article are as follows:

Section 2 is the literature review, summarizing the methods and conclusions about the relationship between smog pollution, public health and family financial burden, and providing related hypotheses. Section 3 is about the materials and methods, introducing the variable measurement, the mediation effect method, data resources and description. Section 4 reveals the result, showing the impact of smog pollution on family financial burden, and the mediation effect of public health on family financial burden. In Section 5, the conclusions and policy implications are provided.

Literature review

The impact of smog pollution on public health

Grossman (1972) took health as an important factor affecting consumer utility to construct the health production function, which became the theoretical basis of the mainstream health research in the field of economics. Cropper (1981) has introduced air pollution into the health production function to study the impact of the environment on health. Moreover, an increasing number of studies are using an epidemiological lens to examine the impact of air pollution on residents' health. Using a sample of 8000 people from six U.S. cities, Dockery et al. (1993) found that the mortality rate of the city with the highest PM2.5 concentration was approximately 1.26 times that of the city with the lowest concentration. Welsch (2002) and Levinson (2012) also shows that smog pollution significantly damages the health status of local residents. For example, Pearce and Warford (1993) proposed that the most immediate consequence of environmental degradation is the threat to public health through various physical or mental illnesses, and even premature death.

The degree of harm to public health from environmental pollution also depends on the level of pollution exposure. Long-term exposure to highly polluted areas is more likely to cause disease following Coneus and Spiess (2012). Shen et al. (2018). Sun et al. (2017) also explore the relationship between air pollution and public health from the perspective of geoeconomics to better assess the impact of air pollution on public health. Katanoda et al. (2011) used a cohort study to explore the health effects of various air pollutants on 63,520 residents in Japan. Katanoda et al. (2011) revealed that the increase in PM2.5, SO_2, and NO_2 concentrations would significantly increase the number of residents dying of lung cancer and respiratory diseases. Crouse et al. (2015) explored the health hazards of different types of pollutants based on the air pollutant

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concentration and resident mortality data in Canada. Crouse et al. (2015) found that among major air pollutants, O_3 and NO_2 had the highest and lowest mortality risks for residents, respectively. The increasing number of epidemiological studies have also allowed researchers to conduct meta-analyses and thereby draw more generalizable conclusions. Aunan et al. explored the impact of PM10 and SO_2 pollution on the health of residents in China using a meta-analysis of the results of 42 studies. Aunan and Pan (2004) found that every 1 $\mu g \cdot m^{-3}$ increase in the concentration of PM10 and SO_2 increased the mortality rate by 0.03% and 0.04%, respectively.

The impact of public health on family financial burden

Research mainly focuses on the direct and indirect economic cost assessment of health loss, or monetary loss, caused by air pollutants. The direct economic cost refers to the direct economic loss caused by air pollution, including the economic loss from premature death, medical expenses, and income losses from missing work. Meanwhile, the indirect economic cost refers to the impact of air pollution at the macro scale, such as the national economy, caused by changes in labor supply and medical expenses. Huang and Zhang (2013) have used quantified the health benefits of reducing air pollution. Among the first such studies, Ridker (1967) estimated that the air pollution-caused health economic loss in the U.S. in 1958 was approximately $80.2 billion. Seethaler et al. (2003) used the willingness to pay method to evaluate the health loss caused by PM10 pollution in Austria, France, and Sweden in Europe in 1996. Seethaler et al. (2003) found that the economic value of health loss was approximately 27 billion euros, accounting for 1.7% of GDP in that year.

The impact of smog pollution on family financial burden

Fan et al. (2020) have noted that via increased mortality and disease burdens, environmental pollution can increase the burden of health costs on households.

Following Bell et al. (2006) and Deschenes et al. (2017) research using quasi-natural experiments with endogenous disturbance of environment and health shows that environmental protection policies can reduce the health risks of pollution to varying degrees by reducing the level of pollution. For instance, empirical studies in Aloi and Tournemaine (2011) using the development-based (R&D) model of growth including pollution externalities and health production sector show that stricter environmental policies can improve workers’ health and develop the economy. In addition, different pollutants have different effects on improving public health. Therefore, Janet and Matthew (2005) showed that environmental policies can reduce environmental pollution-induced diseases or deaths by controlling the concentration of various pollutants, such as PM10, O3, and TSP, and thus, reduce the family financial burden. However, most studies Selden and Song (1994), Grossman and Krueger (1995), Stern (2004), Ebenstein, et al (2015) use linear models to analyze the relationship between environmental pollution and economic development. There are few studies on smog pollution and public health, public health and family financial burden, and even fewer ones on the nonlinear relationship among smog pollution, public health, and family financial burden.

Several studies have discussed the pairwise interactions among smog pollution, public health, and household economic burden, but some issues still need further consideration: First, most studies investigate the direct causal relationship between environmental pollution and public health, and environmental pollution and family

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financial burden in a linear framework. Few undertake quantitative analyses of public health's effect on family financial burden and its non-linear moderating effect on the relationship between environmental pollution and family financial burden. Second, research on the underlying mechanisms of these relationships are not perfect, and the conclusions and policy recommendations on the individual action paths are not comprehensive. These issues serve as the starting point of this article.

Research hypothesis

According to previous discussions, we construct a theoretical analysis model of the action mechanism between smog pollution, public health, and family financial burden, as shown in *Figure 1*. Note that several studies have examined the relationship between smog pollution and public health. Here, we focus on the impact of smog pollution on family financial burden and the role of public health in this process.

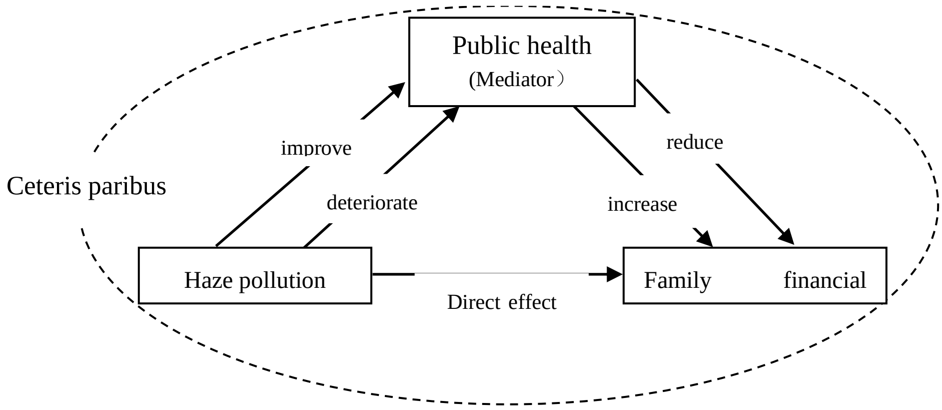

Figure 1. *Theoretical model*

Accordingly, we propose hypotheses H1 and H2 as follows:

Hypothesis 1 (H1). Public health mediates the relationship between smog pollution and family financial burden.

Hypothesis 2 (H2). There is regional heterogeneity in the moderating effect of public health on the relationship between smog pollution and family financial burden.

Materials and methods

The econometric model

In this section, at first, based on the theoretical analysis mentioned above, a benchmark regression model is constructed from *Equations 1–5*. Secondly, variable measurements are described, mainly including the dependent variables, the explanatory variables, the mediating variables, and the control variables. Finally, a brief introduction is given to the Sources of materials including data resources and the descriptions and descriptive statistics about them.

Firstly, we analyze the effect of public health and smog pollution on family financial burden. The benchmark regression model is as follows:

$$fb_{it} = \alpha_0 + \alpha_1 lnphealth_{it} + \alpha_2 lnpm_{it} + B_1 * contr_1 + \mu_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.1)}$$

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Secondly, we analyze whether the interaction between smog pollution and public health affects family financial burden. The benchmark model is as follows:

$$fb_{it} = \beta_0 + \beta_1 lnphealth_{it} + \beta_2 lnpm_{it} + \beta_3 lnphealth_{it} * lnpm_{it} + B_2 * contr_2 + \mu_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.2)}$$

Here, i and t refer to the province and year, respectively; fb represents the family financial burden index; pm represents the weighted average value of haze pollution in each province; $phealth$ denotes the public health index; $phealth * lnpm$ is the interaction term of haze pollution and public health; μ,δ, andεrefer to the individual, time, and random effects, respectively; B_1 and B_2 represent the coefficient parameter vectors of the control variables; α_0 and β_0 are constants; α_1, α_2, β_1,β_2,and β_3 are coefficient parameters; and $contr_1$ and $contr_2$ are the set of control variables.

We hypothesize that public health mediates the relationship between smog pollution and family financial burden. Then, following the intermediate variable test, we construct the following regression models:

$$fb_{it} = \gamma_0 + \gamma_1 lnpm_{it} + B_3 * contr_3 + \mu_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.3)}$$

$$lnphealth_{it} = \varphi_0 + \varphi_1 lnpm_{it} + B_4 * contr_4 + \mu_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.4)}$$

$$fb_{it} = \theta_0 + \theta_1 lm_{it} + \theta_2 lnphealth_{it} + B_5 * contr_5 + \mu_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.5)}$$

Here, γ_0, φ_0, and θ_0 are constants; γ_1, φ_1,θ_1, θ_2, B_3, B_4, and B_5 represent the coefficient parameters, respectively; $contr_3$, $contr_4$, and $contr_5$ represent the set of control variables; and $lnphealth$ is the core mediating variable. Other variables are the same as those in equations (1) and (2). When γ_0 in Equation (3) is significant, it indicates that haze pollution affects family financial burden. Then, when φ_1,θ_1 and θ_2 in equations (4) and (5) are significant, it indicates that haze pollution affects family financial burden partly via public health. However, if φ_1 and θ_2 are significant but φ_1 is not, the effect of haze pollution on family financial burden is entirely due to the public health. Finally, if only one or none of φ_1 or θ_2 are significant, a Sobel or bootstrap test is required to further test the mediating effect.

The variable measurement

The dependent variables

Family financial burden (fb_{it}) is our dependent variable of interest. We focus on 30 provinces and autonomous regions (excluding Chongqing Municipality directly under the Central Government, and Taiwan Province, Hong Kong, and Macao special administrative regions) during the sample period (2008–2022). We compute family financial burden as the weighted average of the ratio of medical and health care expenditure to total household expenditure of urban and rural residents as follows:

$$fb_{it} = urb_{it} w_{uit} + ru_{it} w_{rit} \quad \text{(Eq.6)}$$

Here, urb_{it} and ru_{it} are the ratios of medical and health care expenditure to total household expenditure of urban and rural residents, respectively, in province or region i

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and year t. w_{uit} and w_{rit} are the proportions of urban and rural residents in province i in year t, respectively.

The explanatory variables

We use PM2.5 concentration (pm) as a measure of smog pollution, which is our core explanatory variable. We measure this using the annual mean PM2.5 concentration for each province/region. Epidemiological studies such as Miller et al. (2007), Afshin et al. (2019), Arch Smith et al. (2018) showed that PM2.5 is the most important pathogenic factor in air pollution which seriously affects human health. For instance, proposed that PM2.5 pollution is the eight-leading cause of death in the world. Indeed, as unlike other single pollutants, PM2.5 is a comprehensive indicator of air quality and one of the preferred indicators by many scholars.

Mediating variable

Our mediating variable is public health (phealth). It is measured by the natural logarithm of the province's fiscal health expenditure per capita adjusted by the provincial Consumer Price Index (CPI) with 2000 as the base year. Public health data are relatively scarce in China. Hence, a common method is to measure the health level by certain types of related variables. Most studies, such as Liu et al. (2004), Behrman and Deolalikar (1988), use anthropometric, survival, mortality, morbidity, and overall health and functional status indicators. These include average life expectancy, and infant, under-five, maternal, and population mortality rates. Note that medical and health expenditure is generally declared at the beginning of each upcoming year among the 30 provinces, cities and autonomous regions in China that we focus on. Hence, higher expenditure may not affect economic activities and environmental pollution in the current period, thereby mitigating the endogeneity problem caused by "reverse causality."

The control variables

The set of control variables (contr) includes:

(1) Urbanization rate (urb). The province's urbanization rate in the sample period;

(2) Economic development level (lnpgdp). The natural logarithm of the province's real GDP per capita in the sample period. Real GDP is calculated by dividing the province's nominal GDP by its CPI with 2000 as the base year.

(3) Quality of human capital (hcapital). The ratio of the province's educational expenditure to its GDP in the sample period;

(4) Fiscal autonomy (fiscal). The ratio of the province's fiscal expenditure per capita to the central government's fiscal expenditure per capita in the sample period;

(5) Industrial structure (stru). The ratio of the value added by the tertiary industry of a province to its GDP in the sample period;

(6) Environmental regulation (ers). The ratio of the province's environmental pollution control investment to its GDP in the sample period;

(7) Green space per capita (lnglp). Environmental greening can not only improve air quality, but also positively affect residents' physical and mental health. We use environmental greening as a proxy for the quality of the ecological environment in a province and measure it as the natural logarithm of green space per capita (GLP) in that province;

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(8) The degree of economic openness (open): The ratio of the province's total trade and import volume to China's GDP in the sample period;

(9) Technological progress (tech): The ratio of R&D investment in the province to its GDP in the sample period;

(10) Medical level (lnpdoctor). The natural logarithm of the number of doctors per million people in the province in the sample period; and

(11) Cultural construction (lnbook). The natural logarithm of public library collections per 100 people in the province in the sample period.

The sources of materials

Our data mainly come from the China Statistical Yearbook, China Health Statistical Yearbook, China Environmental Statistical Yearbook, China Economic Network Statistical database, and statistical yearbooks of 30 provinces and autonomous regions from 2008 to 2022. To ensure data availability, we only focus on 30 provinces and autonomous regions, and exclude Chongqing Municipality, Taiwan Province, and Hong Kong and Macao special administrative regions. The PM2.5 concentration data for each province are derived from the annual world PM2.5 density map published by the Battelle Memorial Institute (CIESIN) at Columbia University (2008–2014), and monitoring data from the national urban air quality real-time release platform (2015–2022). Considering that the smog pollution itself has spatial Spillover effect, this study constructs a spatial weight matrixW, and uses the data released by the Ministry of Ecology and Environment of China from 2007 to 2022 to test. The results are shown in *Table 1*: the global spatial autocorrelation index values strongly reject the original hypothesis of "no spatial autocorrelation" at the significance level of 1%, which indicates that there is spatial autocorrelation in smog pollution.

Table 1. *Moran index I and test results of PM2.5 in each province from 2008 to 2022*

Variables	I	E(I)	sd(I)	z	p-value*
pm2.5-08	0.559	-0.040	0.129	4.652	0.000
pm2.5-09	0.589	-0.040	0.127	4.837	0.000
pm2.5-10	0.621	-0.040	0.129	5.112	0.000
pm2.5-11	0.600	-0.040	0.129	4.851	0.000
pm2.5-12	0.571	-0.040	0.128	4.785	0.000
pm2.5-13	0.573	-0.040	0.129	4.731	0.000
pm2.5-14	0.605	-0.040	0.128	5.033	0.000
pm2.5-15	0.593	-0.040	0.129	4.921	0.000
pm2.5-16	0.597	-0.040	0.128	4.963	0.000
pm2.5-17	0.579	-0.040	0.129	4.822	0.000
pm2.5-18	0.578	-0.040	0.130	4.742	0.000
pm2.5-19	0.579	-0.040	0.129	4.745	0.000
pm2.5-20	0.581	-0.040	0.129	5.025	0.000
pm2.5-21	0.583	-0.040	0.129	5.145	0.000
pm2.5-22	0.585	-0.041	0.128	5.142	0.000

The "I" in the table represents the Moran index

Indicators that use monetary values are deflated using the GDP deflator with 2000 as the base year. Mean interpolation is used for missing variables' data. In addition, Stata15.0 is used for econometric analysis. The descriptions and statistical characteristics of the main variables are shown in *Table 2*.

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Table 2. *Descriptions and descriptive statistics of the variables*

Variable	Description	Unit	Mean	Std. dev.	Min	Max
fb	Family financial burden index	%	0.0689	0.1312	0.0367	0.0896
pm2.5	Mean value of PM2.5 in a province	um	3.8359	0.5127	1.5168	4.5329
phealth	Natural logarithm of financial health expenditure per capita in a province	Yuan/person	1.5826	1.4013	0.0017	4.7635
urb	The ratio of urban population to total population in a province	%	0.5512	0.0157	0.3147	0.8762
lnpgdp	Natural logarithm of GDP per capita in a province	Yuan/person	4.1213	1.0511	0.2351	8.3625
hcapital	The ratio of a province's education expenditure to its GDP	%	0.0253	0.0136	0.0011	0.1586
fiscal	The ratio of the fiscal expenditure per capita of the province to that of the central government	%	0.0121	0.0175	0.0000	0.2623
stru	The ratio of the value added by the tertiary industry of the province to its GDP	%	0.3571	0.0812	0.0858	0.8123
ers	The ratio of the province's environmental pollution control investment to its GDP	%	0.0361	0.0237	0.0101	0.0513
lnglp	Natural logarithm the green area per capita in a province	m^2/person	2.5112	3.1215	0.071	7.2538
open	The ratio of province's total import and export volume to China's GDP	%	0.0365	0.0417	0.0000	0.5718
tech	The ratio of the province's R&D investment to its GDP	%	0.0013	0.0016	0.0000	0.0628
lnpdoctor	Natural logarithm of doctors per million people in the province	Person/year	2.2716	0.4562	0.6652	4.5671
lnbook	Natural logarithm of the number of books collected by public libraries per 100 people in the province	Volumes	2.5616	0.8536	0.2115	6.8967

N = 450

Results

Baseline results

Drawn using Stata 15.0, *Figure 2* shows a scatter plot of the relationships between smog pollution, public health, and family financial burden (*Fig. 2*). Smog pollution and family economic burden show a positive relationship, while both smog pollution and public health, and public health and family financial burden show a negative relationship. One may draw a preliminary conclusion that smog pollution affects public health, which in turn affects family financial burden. However, no other control variables are added here. Hence, the scatterplot can only reflect the unconditional correlations. The mediating effect of public health needs to be empirically validated.

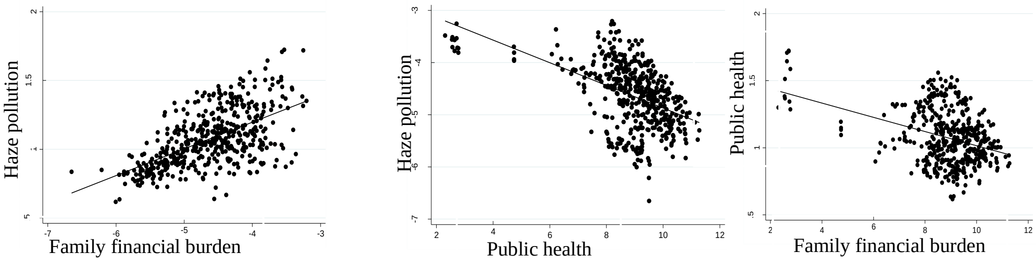

Figure 2. *The scatter plot and fitting straight line between smog pollution, public health, and family financial burden*

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A panel data fixed effects model is used to estimate the benchmark regression models (1) and (2). The results are shown in *Table 3*. Columns 1 and 4 of model (2) do not include control variables for urban economic, social, institutional, and cultural factors. Columns 4, 5, and 6 of model (2) include the interaction term of smog pollution and public health to examine the regulating effect of public health. Control variables are added in Columns 3 and 6 for controlling province-level fixed effects to compare the differences across provinces.

First, comparing the results in columns 1 and 2, and 4 and 5 reveals that after controlling provincial characteristics, both smog pollution and public health significantly affect family financial burden and their absolute coefficient values increase significantly. Provincial characteristics such as economic development level, environmental regulation intensity, and technological progress significantly affect the benchmark regression results. Thus, if we do not consider provincial heterogeneity, we may underestimate the negative impact of smog pollution and public health on family financial burden.

Second, comparing the results in columns 2 and 3, and 5 and 6 shows that although smog pollution and public health significantly affect family financial burden, the change in coefficient is larger. Thus, factors other than the province level control variables affect the relationships between smog pollution, public health, and family financial burden. That is, if we only control the province level variables, we may get biased estimation results.

Finally, comparing columns 2 and 5 shows that adding the interaction of smog pollution and public health significantly enhances the positive (negative) impact of smog pollution (public health) on family financial burden. This means that after removing the regulation effect of public health, the effect of smog pollution and public health on family financial burden strengthens. Meanwhile, the regression coefficient of the interaction term is significantly positive. Thus, smog pollution hinders public health, which in turn reduces family financial burden. Thus, hypothesis H1 is supported.

Table 3. *The baseline main results of models (1) and (2)*

Variables	Dependent variables: fb					
	Model (1)			Model (2)		
	1	2	3	4	5	6
lnpm	0.0215 (0.67)	0.0358^{***} (2.63)	0.0421^{**} (1.93)	0.0237 (0.83)	0.0387^{***} (2.79)	0.0442^{**} (2.21)
phealth	-0.0035^{**} (-2.13)	-0.0039^{**} (-2.17)	-0.0044^{**} (-2.15)	-0.0063 (-0.85)	-0.0219^{***} (-2.81)	-0.0158^{**} (-2.14)
Lnpm × phealth				0.0015 (0.37)	0.0031^{**} (2.31)	0.0029^{*} (1.68)
contr		Y	Y		Y	Y
Time fixed effect	Y	Y	Y	Y	Y	Y
Individual fixed effect			Y			Y
Number of observations	450	450	450	450	450	450
Adjusted R^2	0.9121	0.9175	0.9215	0.9023	0.9215	0.9138

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. t-values are in parentheses

Next, we test the regional differences in the impact of smog pollution on family financial burden, and divide our sample into eastern, western, and central regions in China. To test the regional heterogeneity, we add two region dummy variables into the model: “region1” (1 = middle region, 0 = other regions), “region2” (1 = west region, 0 = other regions). Furthermore, we add interaction terms between regions and smog pollution: lnpm×region1 and lnpm×region2 indicate the interaction terms between smog pollution, and central and western regions, respectively.

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The estimation results are shown in *Table 4*. Across regions, smog pollution increases family financial burden to a great extent. The coefficients for the interaction effects of both dummies are significantly positive. Thus, ceteris paribus, the impact of smog pollution on family financial burden in central and western China is higher than that in eastern China. This can be important for changing the layout of the type of pollution emitted by industrial enterprise across regions during the sample period. Indeed, the provincial distribution of most polluting industries has generally shifted from concentration to dispersion, and from eastern provinces to central and western regions in China since 2008. Thus, hypothesis H2 is supported. Nevertheless, the mechanism between smog pollution and family financial burden in heavily polluted areas is unclear and needs to be further tested.

Table 4. *Estimation results for eastern, western, and central regions in China*

Variables	**Eastern region**	**Central region**	**Western region**	**Including regional dummy variables**
	fb	fb	fb	fb
lnpm	0.0337^{***} (2.76)	0.0353^{*} (1.66)	0.0364^{**} (2.14)	0.0314^{*} (1.58)
phealth	-0.0037^{**} (-2.15)	-0.0048^{*} (-1.57)	-0.0057^{***} (-2.73)	-0.0044^{*} (-1.61)
lnpm × phealth	0.0027^{**} (2.11)	0.0031^{***} (3.26)	-0.0036^{*} (-1.61)	0.0035^{***} (3.78)
contr	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y
Individual fixed effect	Y	Y	Y	Y
Lnpm ×region1	N	N	N	0.0216^{**} (2.05)
Lnpm × region2	N	N	N	0.0469^{***} (5.45)
Number of observations	180	135	135	450
Adjusted R2	0.9136	0.9216	0.9162	0.9158

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. t-values are in parentheses

The mediating effect results

These results show that there may be multiple bidirectional causality between smog pollution, public health, and family financial burden. Thus, endogeneity problems caused by simultaneous causality bias may arise, which makes the estimation results biased and inconsistent. In addition, there may be inconsistent parameter estimates caused by default variables and endogeneity bias. Therefore, we adopt GMM following Arellano and Bond (1991) and Arellano and Bover (1995) and use instrumental variables to address these issues, as well as test whether public health mediates the relationship between smog pollution and family financial burden.

Specifically, we use the differential GMM method to empirically test the mediating effect. The estimation results are reported in *Table 5*. Model (4) reports the estimation result of the impact of smog pollution on family financial burden. Models (5) and (6) list the estimation results of the impact of smog pollution on public health, and of smog pollution and public health on family financial burden, respectively. Finally, the results of AR (2) and Hansen overidentification tests both show that the empirical model is reasonable, and the instrumental variables are valid; thus, the estimated results are statistically reliable.

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First, the results of model (4) show that smog pollution significantly positively affects family financial burden. Specifically, for every 10-fold (1%) increase in smog pollution, family financial burden increases by 0.0331%. Second, the results of Model (5) show that smog pollution significantly negatively affects public health. Specifically, for every 10-fold (1%) increase in smog pollution, public health decreases by 0.0083%. Third, the results for Model (6) show that smog pollution (public health) significantly positively (negatively) affects family financial burden. Specifically, family financial burden increases (decreases) by 0.0342% (0.0049%) for every 10-fold (1%) increase in smog pollution (public health).

Considering the basic principles of the mediation variable test method outlined at the end of the description of the econometric model, the results in *Table 5* show that public health partially mediates the impact of smog pollution on family financial burden. That is, residents in economically developed provinces may have more welfare policy support or less health damage due to policy bias and high health investments, among other reasons, or have greater risk tolerance in the face of homogeneous environmental pollution damage. However, residents in less developed provinces have relatively weaker risk tolerance. Thus, they may fall into a vicious cycle of “pollution-poverty” which may further aggravate their family financial burden in these less developed provinces.

Table 5. *Estimation results for the mediating effect*

	Model (4)	**Model (5)**	**Model (6)**
Variable	fb	phealth	fb
lnpm	0.0331** (2.39)	-0.0083*** (-11.60)	0.0342*** (11.23)
phealth			-0.0049*** (-2.93)
contr	Y	Y	Y
AR (2) -P value	0.276	0.312	0.133
Hansen test-P value	0.167	0.177	0.159
Number of observations	450	450	450

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. t-values are in parentheses. The null hypothesis of AR (2) is that the residual term after difference does not have a second-order serial autocorrelation. The null hypothesis of the Hansen test is that the overidentification test is valid

Conclusions and policy implications

Conclusions

Based on Chinese provincial panel data from 2008 to 2022, this study empirically tested the impact of smog pollution on family financial burden and whether public health mediates this relationship. We constructed a panel data model and used dynamic panel GMM and other empirical methods. Our main conclusions are as follows:

1. Smog pollution increases family financial burden across specifications. Meanwhile, better public health reduces family financial burden. Second, smog pollution damages public health. This can increase residents’ medical expenditure. Meanwhile, it aggravates family financial burden through the partial mediating effect of public health. Third, ceteris paribus, the impact of smog pollution on household family financial burden in central and western China is higher than that in eastern China.

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2. Theoretically, we show the dynamic relationship of "smog pollution-public health-family financial burden". By doing so, we expand and integrate research perspectives on the "smog pollution-public health" and "smog pollution-family financial burden" relationships. In addition, we clarify the transmission path of the influence smog pollution on family financial burden via public health.

3. While our findings are somewhat similar to those of previous studies, there are some key differences. First, we find that smog pollution negatively affects family financial burden, as in Coneus and Spiess (2012). Meanwhile, there is significant regional heterogeneity in the moderating effect of public health and the impact of public health on family financial burden. The effects are heterogenous across regions with different sizes and fiscal autonomy. This result clearly differs from those of early studies, such as Selden and Song (1994).

Finally, this study has some limitations, which provide insights on future research directions. Besides the partial mediating effect of public health, we cannot rule the possibility of other mediators. This can be an important area of focus for future research efforts. Furthermore, researchers can undertake in-depth analysis of mechanisms of public health from the perspectives of health damage and human health capital.

Policy implications

Based on the conclusions above, the policy implications are as follows:

1. Efforts should be made to innovate and improve the compatibility of incentives between local government's economic development efforts and ecological civilization construction in China. First, the government should build a "green GDP" assessment system and increase the weight of environmental protection in the evaluation of government performance. Furthermore, it should clarify the multi-level indicators of pollutant emission in the government performance evaluation system. Second, ecological and environmental authorities should gradually establish a lifelong accountability system for environmental pollution and improve long-term mechanisms of pollution reduction, thereby reducing the pollution-induced damages to public health.

2. The government should establish long-term mechanisms for the comprehensive, systematic, and source prevention and control of smog pollution. A sound ecological environment is the most beneficial to people's wellbeing. As such both developing the economy and protecting the ecological environment are important for people's livelihood. Accordingly, enterprises should be managed in a classified manner and given reasonable guidance to encourage them to increase environmental protection investments and improve the efficiency of emission reduction.

3. Stronger regional cooperation and solid networks for smog pollution prevention and control should be established. These efforts should strengthen information sharing on pollution control, jointly implement special control and control, constantly improve this system, and enhance inter-regional coordination and response for smog pollution prevention and control.

Limitations and future research directions

However, our study has several limitations:

Firstly, due to limited data samples, cross-sectional mixed samples are mainly used for empirical research in this article, and a more suitable panel sample for analysis has not been found. At the same time, in-depth exploration of heterogeneity factors in more

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dimension may also have been ignored. For example, the differences in the impact effects of different spatial scales such as provinces and cities has not been compared and analyzed. These are the main directions for further research in the later stage.

Secondly, health factors into the impact of smog pollution on family financial burden are mainly included this article, and an analytical framework based on this is established. However, other psychological perception factors and other objective influencing factors that affect family financial burden may still have been ignored in the study, so it still needs to be further explored and improved. Therefore, we may have to empirically analyze these in a further study.

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Data availability statement. The data presented in this study are openly available in provincial statistical yearbooks of China, the China Statistical Yearbook, China Health Statistics Yearbook, and China Environmental Statistics Yearbook, available at: http://www.cnstats.org/tjnj/ (accessed on 10 September 2022), http://www.stats.gov.cn/tjsj/ndsj/, (Accessed on 10 September 2022), and http://www.cnstats.org/tjgb/ (accessed on 10 September 2022) or https://www.mee.gov.cn/hjzl/ (Accessed on 10 September 2022); China Economic Network Statistical database, available at: https://db--cei--cn--dwjj. h.gou5juan.com/ (accessed on 10 September 2022); meteorological monitoring data of Columbia University (Socioeconomic Data and Applications Center (SEDAC)), available at: https://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-gwr-pm2-5-modis-misr-seawifs-aod/data-download (Accessed on 10 September 2022).

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