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Environmental regulation effect on health poverty in China

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ABSTRACT

How does government spending on environmental protection benefit people's health? The current paper analyzed 2010 and 2018 data from the China Family Panel Studies (CFPS) database to measure the impact of province-level environmental regulations on the health of local population. The study also applied the Alkire Foster method to develop the multidimensional health poverty (MHP) score, a new index intended to measure the health status of individuals in a holistic manner. Our results indicated that more fiscal spending on environmental regulation could improve health of the local population, especially among low-income population living in the rural areas. Further, the size of health benefit differs by the type of environmental regulation. More specifically, regulations focusing on preventing environmental pollution can achieve more sizable health benefits than remedial ones. Finally, fine inhalable particle ($PM_{2.5}$) has the largest mediating effect on the relationship between environmental regulation and public health. These results provide several policy implications, which highlight the importance of: scaling up fiscal environmental expenditure and optimizing the structure of environmental expenditure with more emphasis on rural areas where more low-income population are located; shifting from ex-post accountability to ex-ante prevention; and strengthening regional cooperation in environmental protection among local governments, and establishing a cross-regional coordination mechanism.

1. Introduction

Good ecological environment is the foundation for human health [1,2]. Social deprivation theory states that environmental pollution is one of the main social threats that deprives our health [3,4], and any negative externalities, such as air pollution, could lead to higher incidences of chronic diseases, e.g., respiratory and cardiovascular diseases [5] as well as mental health problems, such as depression and cognitive and nervous system disorders [6].

Since the Opening-up and Reform in the late 1970s, the rapid growth in China's economy has aggravated significant pollution. Environmental pollution has now become an important topic as the country has to juggle two tasks – seeking further economic development while protecting people's health. Governments, as the supplier of public goods, are obliged to promote environmental and population health by strengthening environmental protection and regulation [7,8]and a good environment is associated with positive externality. With this view, the Chinese government allocates a signification portion of the annual budget to facilitate environmental protection. A large volume of official reports demonstrates the political commitment of China to participate in global health governance and fulfill the Sustainable Development Goals (SDGs) agenda of the United Nations [9,10]. In 2016, the first year of

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the 13th Five-Year Plan, Chinese government only spent 480.29 billion RMB in the annual budget the environmental protection, while in 2021, this number has increased by 14.6 %, reaching 553.6 billion RMB [11]. During this period, both the central and the local governments have increased funding for ecological and environmental protection and provided financial support to reduce pollution, which curbed the environmental pollution significantly [12]. Other than increasing fiscal spending on environmental protection, Chinese government proposed some political terms - building a *Beautiful China* and realizing the *Healthy China* 2030 initiative in many governmental documents [13–16]. As the consequence of environmental spending, health condition of Chinese people has been bettered much and life expectancy in China has improved 5.85 years from 71.6 years in 2000 to 77.4 years in 2019 [17].

In China, Ministry of Ecology and Environment is the state-level authority that enforces environmental regulations and there are province-level, county-level authorities related to environmental regulation under the Ministry of Ecology and Environment. Better-regulated places usually have better environment, for example. Air quality in Beijing has improved significantly in recent years [18] through the stringent environment regulations and resources allocated to remove pollution sources out of the city. Fiscal environmental protection expenditure (FEPE) in the government's annual budget is the most direct proxy for the governmental effort to control pollution in China [19,20]. China's FEPE include those expenditures on: environmental protection management affairs; environmental monitoring and supervision; pollution control; natural ecological protection; energy conservation and utilization; pollution reduction; and many other items.

FEPE is largely broken down into two categories: *preventive expenditures (PE)* and *remedial expenditures (RE)* [21]. The former refers to the fiscal expenditures that facilitate the prevention and monitoring of pollution (e.g., environmental protection management affairs, environmental law enforcement, supervision, natural ecological protection, reforestation and other expenditures), while the latter refers to the fiscal expenditures providing compensations and reliefs to the people whose health deteriorated as a result of pollution (e.g., pollution prevention and control, pollution abatement expenditures) [22]. While prior studies have demonstrated that environmental intervention policies can effectively improve public health by suppressing pollution [23,24], there has been limited research that differentiate the effects of the FEPE expenditure by type, i.e., PE and RE expenditures [25]. The current paper thus aims to elucidate the effects of the preventive and the remedial FEPE expenditures more explicitly. Given that other basic environmental research has compared the effectiveness of preventive and curative treatments in, for instance, of contaminated soil [26] as well as wood deacidification [27], extending the existing environmental regulation research in this direction was deemed particularly meaningful.

In analyzing effects of the two types of expenditures on health, we introduce two additional concepts. First, by applying the Alkire-Foster (AF) method [28], we constructed the multidimensional health poverty (MHP) index, which is comprised of a host of health indicators with different weights and poverty cut-offs to calculate the individual-level health deprivation score. The mean of the MHP index was then calculated to serve as a proxy for the local public health indicator. Second, we applied the Spatial Durbin Model (SDM) [29] in our regression analysis to accommodate the two types of spatial dispersion, including.

(1) **Dispersions of pollution**, referring to the pollution spreading from one area to adjacent areas through the atmospheric and water cycles [30–32]; and
(2) **Intergovernmental competition**, referring to environmental protection strategies of local governments that are interdependent in decision making [33–35].

Spatial Durbin Model (SDM) is an effective tool to estimate the spillover effect of variables that are spatial interdependent and has been widely applied to researches related to public health [36], pollution [37], environmental regulation [38]. Based on the dispersion of pollution and intergovernmental competition, SDM should be used to examine the spatial relation in this paper.

In addition, we examined the mediating role of pollutants in relation to FEPE and the MHP index as a mechanism analysis. In China, industrial wastewater, sulfur dioxide and fine particulate matter ($PM_{2.5}$) are the top three sources that attract wide public concern. Industrial wastewater can contaminate underground domestic water and soil, and industrial sulfur dioxide and fine particulate matter can potentially threaten human respiratory systems in the long-term [39]. Urban and rural areas are suffering from different pollution sources. While urban areas are primarily polluted by atmospheric contaminants, rural areas are seriously threatened by water and soil pollutants. However, due to atmospheric motion and water circulation, atmospheric pollution can be transformed into water and soil pollution, deteriorating public health through several channels, including air, water, and food.

2. Materials and method

2.1. Data and variables

The current study utilized the individual-level health records collected between 2010 and 2018, which were part of the proprietary China Family Panel Studies [40] database. After cleaning and excluding the observations with a large number of missing values, the final panel data contained 4120 individuals aged 16 or above, located across 25 provinces in China. Additional variables were merged to the data, including the province-level data on financial environmental protection expenditures and their classifications collected from the China Statistical Yearbook, and the province-level control variables obtained from the China Environmental Yearbook and the wind database. These variables are described below.

(1) Response variable: Multidimensional Health Poverty (MHP) index

The MHP was developed using the afore mentioned database between 2010 and 2018. The MPH index calculations involved 3 sequential steps [41]. First, we introduced a binary health-related deprivation indicator, g_{ij}, which takes the value 1 if $X_{ij} > Z_j$, indicating that X_{ij}, the individual i's deprivation score in dimension j (j=1, ...,D), is larger than a given threshold level $Z_j > 0$ (Table 1), and $g_{ij} = 0$ if $X_{ij} < Z_j$. Second, after determining the health deprivation level in all dimensions, we aggregated them to estimate the individual-level MHP scores for all individuals. Here, we set the weight of dimension j as w_i, $\sum_{j=1}^{D} w_i = 1$. We used the principal component analysis (PCA) to calculate the weights of the dimensions. The individual-level MHP index was then summarized as $C_i(g) = \sum_{j=1}^{D} w_i g_{ij}$. Third, we calculated the mean of the individual-level MHP scores in each province as the province-level MHP score where a higher score corresponds to the worse health in the province.

The MPH index, as a proxy of public health, includes three dimensions and seven indicators [42,43]. Table 1 summarizes the dimensions and indicators used to calculate the MPH index and the weights, in which chronic diseases accounting for a relatively large weight, followed by dynamic health and mental state.

We used the principal component analysis (PCA) to determine the weights of the dimensions. First, we prepare the data and standardize them before performing PCA. Second, we retrieve the component loadings and explained variance ratios from the fitted model after performing PCA. Higher explained variance ratios indicate a more significant impact of a component on the overall variance. Third, to assign weights to each index component, we first normalize the component loadings to sum up to 1 for each component. Fourth, we calculate the weights for each index indicator in our dataset by using the first principal component loadings.

(2) Explanatory variable: Environmental Regulation

The level of Environmental Regulation (ER_{pt}) was proxied for the years between 2010 and 2018 using the Fiscal Environmental Protection Expenditure. Some prior literature uses Fiscal Environmental Protection Expenditures as a proxy of regional environmental regulation [44,45]. Fiscal Environmental Protection Expenditures is a monetary indicator that measure how the government exert policies and regulations on protecting environment and the data is more accessible than other proxies. This account includes expenditures on environmental protection management affairs, environmental monitoring and supervision, pollution control, natural ecological protection, returning farmland to forest, energy conservation and utilization, and pollution reduction. Environmental protection expenditures can be divided into two types, i.e., preventive expenditures (pre_{pt}) and remedial expenditures ($post_{pt}$). The former refers to the expenditures that occur *before* environmental pollution, and are intended for preventing the spread of pollution. These include environmental protection management affairs, environmental law enforcement, supervision, natural ecological protection, reforestation and other expenditures that occur before the environmental pollution that is harmful to health. The latter refers to expenditures that occur *after* environmental pollution, and are intended for reducing the environmental pollution, including pollution reduction expenditures. Fiscal environmental protection expenditure is calculated as the logarithm of the total fiscal environmental protection in province p in year t deflated by the CPI index in 2009. In addition, we did not use the fiscal expenditure of environmental protection by per capita because the fiscal expenditure of environmental protection benefits the whole area or province, and thus we cannot clearly figure out how much benefit one individual living in that area receive from the environmental expenditure. Instead, we used the log of fiscal expenditure of environmental protection as the explanatory variable.

(3) Control variables

Multiple control variables, as summarized in Table 2, were developed for the years between 2010 and 2018. Our control variables included a series of demographic factors and social economic factors that may affect public health [46,47]. In addition, both province and year effects were included to adjust for any space and time factors correlated with the dependent variable. The explanatory variable, control variables and the annual emission of industrial wastewater and industrial sulfur dioxide can be found in the database of National Bureau of Statistics of China. Another mediating variable, the annual average of fine particulate matter (PM2.5), can be calculated by using the database of Ministry of Ecology and Environment.

Table 1
Multidimensional Health Deprivation index and weights.

Dimensions	Indicator	Explanations and cutoffs	Weights (%)
Health assessment	Self-assessment health	Respondent rates own health status from 1 (very poor) to 5 (very good), less than 3 means being deprived in this dimension	13.053
	Interviewer-assessment health	Interviewer rates respondent's health status from 1 (very poor) to7(very good), over 4 means being deprived in this dimension	9.934
Body health	Chronic disease	During the past six months, respondent is diagnosed chronic disease, which means being deprived in this dimension	20.313
	Dynamic health	current health status compared to a year ago, becoming worse means being deprived	19.011
Mental health	Spiritual status	I am in a low spirit, often (3–4 days) or most of the time (5–7 days) means being deprived	17.354
	Life satisfaction	satisfied with your life, rating from 1 to 5 means very unsatisfied to very satisfied, over 3 means being deprived	10.346
	Future confidence	Confident about your future, rating from 1 to 5 means very confident to very confident, over 3 means being deprived	9.989

Table 2
Summary of variables.

Variables	Explanation	mean	Std	min	max
Multidimensional Health Poverty	The multidimensional health poverty index calculated in 2.1.(1)	0.273	0.014	0.003	0.930
Environmental regulation	Explained in 2.1.(2)	5.141	0.645	2.782	6.620
Preventive expenditure	Explained in 2.1.(2)	4.412	0.558	1.994	5.533
Remedial expenditure	Explained in 2.1.(2)	4.893	0.502	2.330	5.802
Male-to-female ratio	The male population divided by the female population of a province (%)	104.751	3.867	98.230	118.620
Death rate	death toll over a year divided by the annually average population of a province (%)	0.603	0.077	0.421	0.754
Population density	The population of a province(million) divided by the area of a province (thousand km^2)	439.411	634.058	2.659	3535.714
Urbanization rate	The urban population divided by the population other than urban population of a province	0.561	0.137	0.227	0.893
Unemployment Rate	The registered unemployment population divided by the working population of a province	0.033	0.006	0.013	0.045
Healthcare capacity	The number of medical professionals in 10,000 residents of a province	0.008	0.002	0.004	0.015
Economy growth	The logarithm of GDP per capita of a province in one year, deflated by the CPI index in 2009	9.552	1.018	6.240	11.512

2.2. The model

The Spatial Durbin Model (SDM) includes spatial lags of explained and explanatory variables in the regression model to address the cross-sectional dependence problem [48–50]. In this paper, the SDM was used to examine the spatial effect of environmental regulation on public health, as specified below.

$$MHP_{pt} = \rho W_p MHP_t + \beta_1 ER_{pt} + \beta_2 W_p ER_t + \beta_3 Controls_{pt} + \varepsilon_{pt},$$

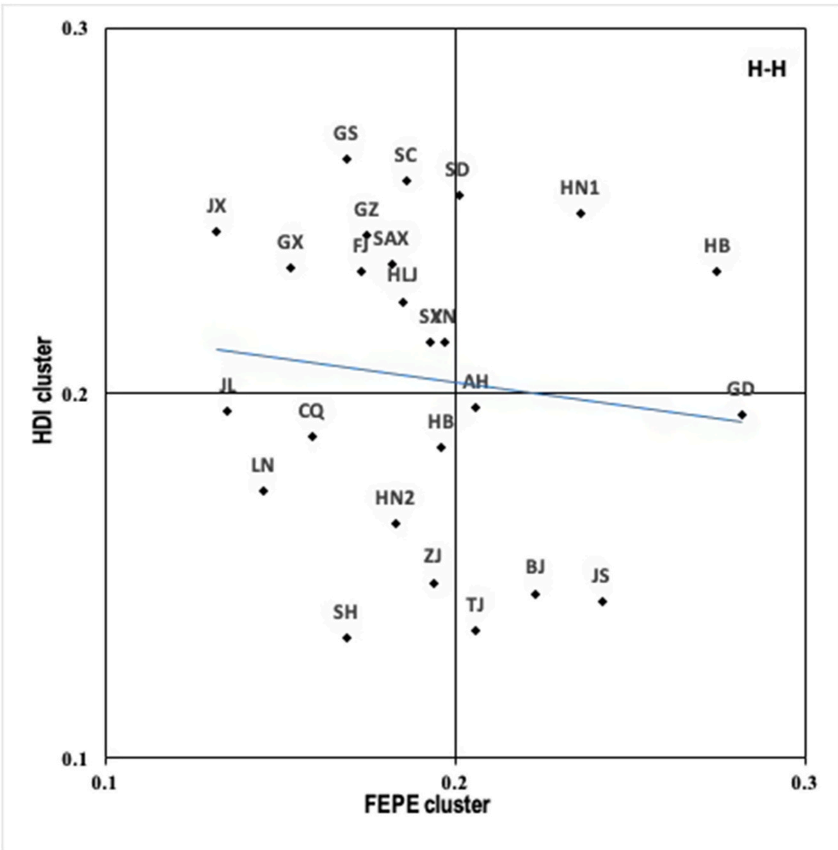

Fig. 1. The local Moran's I Scatterplot of environmental regulation and MHP index in 2018.

where ρ denotes the spatial autoregressive coefficient of the spatial lag term of multidimensional health deprivation, measuring the effect of the public health in the neighboring provinces on that in their own provinces. β_1 denotes a coefficient of fiscal environmental protection expenditure on public health. W is a standardized spatial weighted row matrix ($n \times n$, where n is the number of provinces), describing the adjacency relationship between two regions, i.e., when province p and province q are adjacent, $\omega = 1$, and otherwise $\omega = 0$. β_2 denotes a spatial autocorrelation coefficient of fiscal environmental protection expenditure, which measures its spillover effect on the public health in neighboring provinces in the province to p and on time to t. ε_{pt} is the model error in the province to p and on time to t.

Environmental regulation could improve the living environment by effectively reducing pollutant emissions, which, in turn, could reduce the occurrence of physical diseases and improves public health. It has been found that environmental pollutants have negative effects on health (Noonan, 2014; Miller and Newby, 2020). Other than the basic spatial regressions, we also executed the non-parametric percentile bootstrapping sampling method, with the number of samples 1,000, to examine the mediating effect of the emissions of three major pollutants - industrial wastewater (waste), industrial sulfur dioxide (SO_2), and provincial air pollution index by annual average ($PM_{2.5}$), between the relation of the environmental regulation and the MHP scores. The indirect effect of the pollutants reveals the mechanism of how the FEPE improves public health [51,52].

3. Results

3.1. Spatial correlation test on fiscal and environmental expenditure and public health

The global Moran's I index of fiscal environmental protection expenditure from 2010 to 2018 fluctuated between 0.225 and 0.251. The positive spatial dependence indicates that the fiscal environmental protection expenditure of one province was positively influenced by the fiscal environmental protection expenditure of its adjacent province. The global Moran's I index of MHP index from 2010 to 2018 increased from 0.154 to 0.182. The positive spatial dependence indicates that the public health of a province positively impacted by that of neighboring provinces.

The local Moran's I scatterplot (Fig. 1) presents a negative spatial correlation between fiscal environmental protection expenditure and public health deprivation, indicating that the higher the fiscal environmental protection expenditure, the better the health of the

Table 3
Spatial effects of total and structure of environmental regulation on public health.

Variables	total	urban	rural	total	urban	rural
	(1)	(2)	(3)	(4)	(5)	(6)
ρ	0.183* (0.108)	0.075* (0.043)	0.199* (0.109)	0.234*** (0.015)	0.176*** (0.017)	0.105*** (0.018)
Environmental regulation	−0.046** (0.019)	−0.012** (0.005)	−0.071** (0.031)			
ω • Environmental regulation	−0.014** (0.006)	−0.011** (0.007)	−0.025** (0.011)			
Preventive expenditure				−0.113*** (0.007)	−0.186** (0.078)	−0.065** (0.028)
Remedial expenditure				−0.024*** (0.001)	−0.012** (0.005)	−0.034** (0.016)
ω • Preventive expenditure				−0.120* (0.069)	−0.135** (0.056)	−0.053** (0.022)
ω • Remedial expenditure				−0.045*** (0.006)	−0.021*** (0.002)	−0.048* (0.027)
Male-to-female ratio	−0.012* (0.006)	−0.007*** (0.002)	−0.017* (0.009)	−0.051* (0.027)	−0.032** (0.014)	−0.058** (0.026)
Death rate	0.002*** (0.000)	0.001*** (0.000)	0.004*** (0.000)	0.004*** (0.000)	0.005*** (0.000)	0.002*** (0.000)
Population density	−0.053*** (0.004)	−0.018** (0.008)	−0.114*** (0.011)	−0.052*** (0.007)	−0.043*** (0.011)	−0.097*** (0.020)
Unemployment Rate	−0.165*** (0.013)	−0.177** (0.002)	−0.136*** (0.016)	−0.120* (0.068)	−0.105** (0.043)	−0.159** (0.079)
Urbanization rate	−0.177*** (0.017)	–	–	−0.027*** (0.004)	–	–
Healthcare capacity	−0.082* (0.045)	−0.079* (0.046)	−0.144* (0.075)	−0.042* (0.024)	−0.040** (0.016)	−0.050* (0.028)
Economy growth	−0.852*** (0.129)	−0.743*** (0.048)	−1.064** (0.447)	−0.220** (0.102)	−0.152* (0.088)	−0.243** (0.110)
Year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Province	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Ad-R2	0.366	0.295	0.301	0.288	0.181	0.230
Log-L	459.298	199.409	337.636	259.312	199.409	241.808

Note: ***, **, and * indicates the significance at the 1 %, 5 %, and 10 % levels, respectively, and the number in parentheses are standard deviations, as in the following tables.

population in the province and the neighboring provinces. Thus, fiscal environmental protection expenditure helps to alleviate health deprivation and improve public health.

3.2. Spatial effect of total fiscal environmental protection expenditure on public health

The regression results of the total fiscal environmental protection expenditure are shown in Models 1–3 in Table 3. First, there was a positive spatial autocorrelation of the MHP index ($\rho = 0.183$, $p = 0.108$). Thus, the higher MHP index of one province leads to the higher MHP index of the neighboring provinces, implying that improving the public health in one neighboring province can improve that in the neighboring provinces. The result also indicated that this spatial dependence has an urban-rural difference. Specifically, the spatial cluster of public health of rural residents ($\rho = 0.199, p = 0.109$) was higher than that of urban residents ($\rho = 0.075, p = 0.043$). Presumably, this is due to the dispersed and yet interconnected rural areas across contiguous counties, while cities are relatively isolated and fragmented in their distribution. Second, there is a negative spatial spillover effect ($\beta = -0.014$, $p = 0.006$) of the environmental regulation on the MHP index in its neighboring province, which means the environmental regulation in one province can significantly improve public health in its neighboring provinces. Third, the significant negative effect of fiscal environmental protection expenditure on the province-level MHP index indicates that this government spending can improve the public health of an area, and the welfare effect on residents is revealed ($\beta = -0.046$, $p = 0.019$).

3.3. Spatial effects of breakdowns of environmental regulation on public health

The spatial effects of preventive and remedial expenditures on the health of residents and the urban-rural differences was also analyzed. As Models 4–6 in Table 3 indicates, both preventive ($\beta = -0.113$, $p = 0.007$) and remedial environmental regulation ($\beta = -0.024$, $p = 0.001$) had negative spatial spillover effects on the MHP index of residents in neighboring provinces. The negative spillover effect was, however, larger for preventive environmental spending ($\beta = -0.120$, $p = 0.069$) than the remedial one ($\beta = -0.045$, $p = 0.006$), indicating that preventive environmental regulation inhibits the spatial spread of environmental pollution and improves the health of residents in neighboring provinces. In the urban-rural comparison, there were different effects of the two types of environmental regulation on the health of urban and rural populations. Between the two, preventive environmental regulation had a larger effect on improving the health of urban population ($\beta = -0.186$, $p = 0.078$), while remedial one was more effective in rural population ($\beta = -0.034$, $p = 0.016$). In addition, the negative spillover effect of preventive environmental regulation was greater in urban areas ($\beta = -0.135$, $p = 0.056$), while the negative spillover effect of remedial one was larger in rural areas ($\beta = -0.048$, $p = 0.027$).

3.4. Robustness test

In order to test the reliability of the effect of environmental regulation on public health, we implemented a Spatial Lag Model (SLM) using the geographical distance weight matrix of provincial capitals and a Spatial Error Model (SEM) to test the spatial effect of provincial environmental regulation on the MHP index of residents under the full sample. Table 6 shows that fiscal environmental expenditures have a significant improvement on public health (SLM: $\beta = -0.165$, $p = 0.004$; SEM: $\beta = -0.087$, $p = 0.038$) and preventive environmental expenditures have a stronger effect (SLM: $\beta = -0.158$, $p = 0.006$; SEM: $\beta = -0.155$, $p = 0.012$) than remedial environmental expenditures. This finding is consistent with the SDM model test results, which proves the robustness of the baseline regression results. To analyze the sensitivity of results to the changing weights, we used the entropy method to calculate a new set of weights of the MHP dimensions. Table 4 presents that results remains consist with the prior robust test results when the weights of the MHP dimensions are changed.

Table 4
Robustness test of the effect of environmental regulation on public health.

Variables	SLM		SEM		Entropy method	
	(1)	(2)	(3)	(4)	(5)	(6)
λ/δ	0.054*** (0.001)	0.201*** (0.012)	0.051*** (0.011)	0.261*** (0.039)	0.032** (0.015)	0.143** (0.073)
Environmental regulation	−0.165*** (0.004)	–	−0.087** (0.038)	–	−0.067* (0.036)	−0.054* (0.031)
Preventive expenditure	–	−0.158*** (0.006)	–	−0.155*** (0.012)	–	0.143** (0.071)
Remedial expenditure	–	−0.114*** (0.020)	–	−0.129*** (0.025)	–	−0.107* (0.060)
Ad-R²	0.264	0.177	0.234	0.291	0.232	0.205
Log-L	326.511	297.987	303.087	218.080	253.654	223.352

Table 5
Subgroup analysis by income of the health effects of environmental regulation.

Variables	High	Mid-high	Mid	Mid-low	Low
	(1)	(2)	(3)	(4)	(5)
ρ	0.025***	0.052***	0.100***	0.196***	0.201***
	(0.006)	(0.005)	(0.011)	(0.028)	(0.008)
Environmental regulation	−0.005***	−0.028***	−0.041***	−0.121***	−0.261*** (0.009)
	(0.001)	(0.002)	(0.009)	(0.006)	
ω • Environmental regulation	−0.011*	−0.035***	−0.105*	−0.150***	−0.185***
	(0.006)	(0.012)	(0.061)	(0.009)	(0.014)
Ad-R^2	0.220	0.206	0.268	0.285	0.231
Log-L	318.098	392.524	301.227	266.325	306.089

Table 6
Subgroup analysis by geographical location of the health effects of environmental regulation.

Variables	East	Central	West
	(1)	(2)	(3)
ρ	0.012***	0.034***	0.053***
	(0.000)	(0.001)	(0.003)
Environmental regulation	−0.010*	−0.005**	−0.002***
	(0.005)	(0.002)	(0.000)
ω • Environmental regulation	−0.001*	−0.003*	−0.001**
	(0.000)	(0.001)	(0.000)
Ad-R^2	0.183	0.190	0.152
Log-L	311.009	243.252	233.927

4. Further analysis

4.1. Subgroup analysis by income

To examine the effects of environmental regulation on public health by income class, we divided the sample into five groups based on the percentile level of annual personal income. The results in Table 5 show that environmental regulation has the highest health benefits and spatial spillover for the low-income group ($\beta = -0.261, p = 0.009$), and a lowest health benefit for the high-income group ($\beta = -0.005, p = 0.001$). This may be because low-income groups tend to have a poorer quality of living environment and are more exposed to the threat of environmental pollution, so the fiscal environmental protection expenditure can improve their health more effectively. The middle and high-income groups usually have a better living environment and are resistant to environmental pollution, so the marginal health benefits in this group may relatively be small. The population with a lower economic background is, in general, more likely to suffer from a higher level of air pollution due to a poorer living environment, and this inequality seems to exist not only in the level of exposure to environmental hazards, but also in the right to access to beneficial environments [53].

4.2. Subgroup analysis by geographical location

Geographical location is another factor that is likely to differentiate the health effect of environmental regulation. To examine the effects of environmental regulation on public health by geographical location, we divided the sample into three groups – East China, Central China and Western China. East China section consists of coastal provinces and municipalities, where experiencing humid maritime climate and less temperature variance. Central China is made of several provinces that sandwiched between both the eastern part and the western part. And the Wester China comprises the provinces that are far away from the ocean and shows a continental arid climate. Ground-level pollutants are highly susceptible to temperature variations and humidity, and the geographical location leads to the climate difference. Hence, we need to examine how the health effects vary among the samples in different geographical location. The results in Table 6 present that environmental regulation has the highest health benefits for the East China group ($\beta = -0.010, p = 0.005$), and a lowest health benefit for the Western China group ($\beta = -0.002, p = 0.000$). It is because the environmental spending in East provinces is higher than Central China and Western China and the environmental regulation is more stringent than the other parts. In addition, the spillover effect of the environmental regulation ($\beta = -0.003, p = 0.001$) and the spatial cluster of public health of Central China ($\rho = 0.034, p = 0.001$) was higher than that of other two areas. It is due to that the samples in Central China are more interconnected and interdepend than the East and West China.

4.3. Mechanism analysis

This section aimed to investigate the underlining mechanism that environmental regulation improves public health. Table 5 summarizes the results of our mechanism analysis. It shows that industrial wastewater, industrial sulfur dioxide, and fine particulate matter have significant mediating effects on the relationship between environmental regulation and public health in the following descending order: (1) fine particulate matter (-*Indirect* =0.120, *L*=-0.141, $U = -0.102$); (2) industrial sulfur dioxide (*Indirect*=-0.106, *L*=-0.116*,* $U = -0.096$); and (3) industrial wastewater (*Indirect*=-0.038, *L*=-0.051*,* $U = -0.015$). The results indicate that environmental regulation can effectively reduce air pollution and industrial wastewater emissions, optimizing ecological and environmental management, which in turn effectively improves public health Table 7.

5. Conclusions and discussions

Our results demonstrated that the total fiscal environmental protection expenditure can remarkably improve the public health. The fiscal environmental protection expenditure in 2018 increased by 161.9 % compared with 2010, especially the two increasing accounts of expenditure, i.e., pollution reduction and renewable energy. These accounts effectively ameliorated the quality of the ecological environment and reduced the pollution of land, water resources, and atmosphere, thereby eventually reducing the incidence of chronic diseases and improving the public health. The comparison between urban and rural areas indicates that fiscal environmental protection expenditure has a stronger inhibitory effect on the MHP index of rural residents. We opine that this reflects the increasingly strict environmental regulations in cities that have made many heavy polluting firms move to rural areas. Thus, rural areas may suffer a high incidence of environmental pollution accidents, coupled with their economical backwardness. The health of rural residents is relatively more vulnerable and sensitive to pollutants, and thus environmental pollution shock is more likely in rural population.

Due to the diffusion of harmful pollutants, fiscal environmental protection expenditure can curb that spread in one region, which indirectly reduces the harm to other regions and improves public health in neighboring provinces. In the urban-rural comparison, the spillover effect of financial environmental protection spending on the health of rural residents is greater than that of urban residents. This indicates that the government should take environmental protection as a systematic project, establishing the regional environmental protection consultation and cooperation mechanism, and trying to alleviate the tension or contradiction caused by intergovernmental competition and strengthen the synergy of cross-provincial protection.

Moreover, our results demonstrated that two types of breakdowns of environmental regulation have different health effect on public health. Preventive environmental regulation can reduce the incidence of environmental pollution incidents, while remedial spending requires the government to spend more financial resources to compensate for the negative consequences of the pollutants. Our results also indicated that the urban and rural populations disproportionally receive the health benefits from the two types of environmental regulation. The health effect of preventive environmental regulation is larger in urban areas where environmental monitoring is more stringent. In contrast, the health benefit from remedial regulation is larger in rural areas where the incidence of polluting environmental incidents is higher. With this view, the government should increase the proportion of preventive environmental expenditures and shift the focus from post-event remediation to pre-event prevention.

Two sub-accounts of environmental regulation on public health could produce different spatial effects on public health of the urban samples and rural samples. This is mainly due to the fact that, in recent years, cases of serious ecological damage have exhibited a tendency to be transferred from one province to its neighboring one. When the government strengthens its efforts to protect the environment in its own places and intensifies monitoring and prevention of all types of potential pollution, it reduces the possibility of large pollution occurrence and transfer at source, ultimately benefiting the public health in neighboring cities. Similarly, when ecologically damages occur, the government begins to increase its efforts in remedial activities in rural areas, which not only improves the speedy recovery of the health of the province but also the health of neighboring provinces by preventing the deterioration and spread of environmental consequences.

We acknowledge six limitations in the current study. First, we did not acquire the county-level data of resident's health and the fiscal environmental spending due to the disclosure of the database. Instead, we used the provincial-level data, which failed to unveil a more granular, local-level phenomenon of public health. Second, the samples size of this research might not be large enough to accurately estimate the results and generalize the conclusion to the entire or other country populations. We should note, however, that the CFPS database used in this paper is a nationally representative, biannual longitudinal survey of Chinese communities, families, and individuals launched in 2010 by the Institute of Social Science Survey (ISSS) of Peking University, China, and was the best available data for the current study. Third, the MPH index contains limited information to be a defensive index. Our MPH index captures three dimensions and seven indicators where each indicator is supported by prior literature [54,55]. The development of the MPH index reflects our effort to integrate these seven indicators into one measure, and thus further effort is needed to develop a more comprehensive measure for health. Fourth, we acknowledge that the scope and the scale of the dispersion of pollutants is directly impacted by the balance of these different polluters in a particular geographic area. Due to the availability of the data, we could not differentiate point sources of pollution such as steel mills versus nonpoint sources such as private vehicles, which may also impact the dispersion of pollutants. Fifth, the finding of negative spatial spillover effect of regulation on public health does not necessarily indicate the causality, which is a limitation inherent to all conventional statistical analysis. Finally, while we focused on ex-post and ex-ante

Table 7
Mediated effects of industrial wastewater, industrial SO_2, and $PM_{2.5}$.

Variables	Total	Direct	Indirect	95 % confidence interval (L , U)	
Waste	−0.102***	−0.064***	−0.038***	−0.051	−0.015
SO_2	−0.248***	−0.142**	−0.106***	−0.116	−0.096
$PM_{2.5}$	−0.238***	−0.118***	−0.120***	−0.141	−0.102

environmental regulations in the current study, we acknowledge that there are diverse approaches in regulating different types of pollution, including permits to control point-source pollution as well as incentive programs to reduce nonpoint source pollution. The ways in which these different regulations are enforced clearly influence the pattern of pollution diffusions. One good direction of future research would be to look into how a diverse set of environmental policies and regulations effectively reduce different types of pollution.

6. Policy implications

In this paper, we used the China Family Panel Survey (CFPS) from 2010 to 2018 to construct a MHP index and applied a spatial econometric model to test the province-level fiscal environmental protection expenditure on the health of local populations. Based on the findings and discussions above, the following policy implications are proposed.

First, the government should continue to scale up the spending to achieve the goal of ecological civilization construction. During the 13th Five-Year Plan period, the fiscal environmental protection expenditures reached a cumulative total of RMB 3061.8 billion, excluding the year 2020, which was hit by the Covid-19 pandemic, with an average annual growth rate of more than 15 % from 2016 to 2019, and the ratio of environmental protection expenditures to total fiscal budget expenditures grew from 2.67 % to 3.12 %. Although it has continued to grow in recent years, the fiscal environmental protection spending in China only recorded at about 0.7 % of GDP in 2021. Compared to some developed countries, this ratio is still low. The outline of the 14th Five-Year Plan puts the construction of ecological civilization in a more prominent position, promotes green development and the harmonious coexistence of man and nature. Therefore, the governments at all levels should take a leading role in the construction of ecological civilization and scale up financial expenditure on environmental protection is a practical guarantee to achieve the goal of ecological civilization.

Second, the government continues to optimize the structure of fiscal environmental protection expenditures and shift from ex-post accountability to ex-ante prevention. The Article 5 of China's Environmental Protection Law also establishes the basic principles of putting protection first, stringent prevention, and comprehensive treatment. With this view, the local governments should shift their environmental protection strategy from ex-post accountability to ex-ante prevention, and switch the focus of spending from pollution treatment to ecological protection and energy conservation. The government should continue to expand the preventive input on ecological protection, energy conservation, emission reduction, waste classification, and increase the proportion of preventive spending and strengthen the support of special funds for environmental protection to nip the hidden dangers in the bud.

Third, the local government should strengthen regional cooperation in environmental protection and establish a cross-regional coordination program. In China, pollutants such as waste gas and wastewater are spatially diffuse, and plus the increasingly frequent movement of population, environmental protection in a region cannot be solely counted on a single local government but also a interactive project for every local government. It is necessary to clarify the responsibility among local governments and build a fiscal and taxation system that is proportional to the administrative burden of the government and design a reasonable inter-regional transfer payment and ecological compensation system, and to motivate local governments to participate in inter-regional cooperation. The provincial governments should further improve the cross-regional ecological and environmental protection coordination in coordination under the central government and improve the early warning and monitoring system for air and water pollution, and effectively form a strong synergy for environmental regulation to vigorously build a healthy China in the 14th Five-Year Plan period.

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Additional information

No additional information is available for this paper.

Data availability statement

The data used in this study are available in the PKU open research data platform China Family Panel Studies (CFPS): https://opendata.pku.edu.cn/dataverse/CFPS?language=en.

CRediT authorship contribution statement

Luqing Fan: Writing – original draft, Methodology, Data curation, Conceptualization. **Xiaojia Li:** Writing – review & editing, Supervision, Funding acquisition. **Naoru Koizumi:** Writing – review & editing, Supervision.

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.

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References

[1] L.W. Green, L. Richard, L. Potvin, Ecological foundations of health promotion, Am. J. Health Promot. 10 (4) (1996) 270–281, https://doi.org/10.4278/0890-1171-10.4.270.
[2] K. Tzoulas, K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kaźmierczak, J. Niemela, P. James, Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review, Landsc. Urban Plann. 81 (3) (2007) 167–178, https://doi.org/10.1016/j.landurbplan.2007.02.001.
[3] Nyiwul Mabughi, Tarek Selim, Poverty as social deprivation: a survey, Rev. Soc. Econ. 64 (2) (2006) 181–204, https://doi.org/10.1080/00346760600721122.
[4] H.J. Smith, T.F. Pettigrew, Advances in relative deprivation theory and research, Soc. Justice Res. 28 (1) (2015) 1–6, https://doi.org/10.1007/s11211-014-0231-5.
[5] Mark R. Miller, David E. Newby, Air pollution and cardiovascular disease: car sick, Cardiovasc. Res. 116 (2) (2020) 279–294, https://doi.org/10.1093/cvr/cvz228.
[6] D.S. Noonan, Smoggy with a chance of Altruism: the effects of ozone alerts on outdoor recreation and driving in atlanta, Pol. Stud. J. 42 (1) (2014) 122–145, https://doi.org/10.1111/psj.12045.
[7] R. Gupta, Prevention and control of air pollution: legislative and administrative frame work in India, Asian Journal of Multidimensional Research 9 (2) (2020) 56–62, https://doi.org/10.5958/2278-4853.2020.00017.8.
[8] S.E. Holtermann, Externalities and public goods, Economica 39 (153) (1972) 78–87, https://doi.org/10.2307/2552058.
[9] Original CSET Translation of "(Authorized Release) Proposal of the Central Committee of the Chinese Communist Party on Drawing up the 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2030, Xinhua News Agency, 2020. November 3, https://cset.georgetown.edu/publication/proposal-of-the-central-committee-of-the-chinese-communist-party-on-drawing-up-the-14th-five-year-plan-for-national-economic-and-social-development-and-long-range-objectives-for-2030/.
[10] State Council of the People's Republic of China, Report on the Work of the Government (2022). https://english.www.gov.cn/premier/news/202203/12/content_WS622c96d7c6d09c94e48a68ff.html.
[11] National Bureau of Statistics of China, National Data (2023). https://data.stats.gov.cn/easyquery.htm?cn=C01.
[12] Ministry of Ecology and Environment of the People's Republic of China, Report on the State of the Ecology and Environment in China 2020 (2022). http://english.mee.gov.cn/Resources/Reports/soe/SOEE2019/202204/P020220407417638702591.pdf.
[13] World Health Organization, The 9th Global Conference on Health Promotion, Shanghai (2016). https://www.who.int/teams/health-promotion/enhanced-wellbeing/ninth-global-conference/healthy-china.
[14] X. Tan, Y. Zhang, H. Shao, Healthy China 2030, a breakthrough for improving health, Global Health Promotion 26 (4) (2019) 96–99, https://doi.org/10.1177/1757975917743533.
[15] C. Fang, Z. Wang, H. Liu, Beautiful China Initiative: human-nature harmony theory, evaluation index system and application, J. Geogr. Sci. 30 (2020) 691–704, https://doi.org/10.1007/s11442-020-1750-7.
[16] J. Wang, Environmental Protection in China in the Past 70 Years, Beautiful China: 70 Years Since 1949 and 70 People's Views on Eco-civilization Construction, 2021, pp. 35–45, https://doi.org/10.1007/978-981-33-6742-5_3.
[17] World Health Organization, Environmental Protection in China in the Past 70 Years, Beautiful China: 70 Years Since 1949 and 70 People's Views on Eco-civilization Construction, 2024, pp. 35–45, https://doi.org/10.1007/978-981-33-6742-5_3.
[18] UN Environment, A Review of 20 Years' Air Pollution Control in Beijing (2019). https://www.unep.org/resources/report/review-20-years-air-pollution-control-beijing.
[19] G.E. Halkos, E.A. Paizanos, Environmental macroeconomics: economic growth, fiscal spending and environmental quality, International Review of Environmental and Resource Economics 9 (3–4) (2016) 321–362, https://doi.org/10.1561/101.00000079.
[20] W. Sheng, L. Wan, C. Wang, The spillover effect of fiscal environmental protection spending on residents' medical and healthcare expenditure: evidence from China, Environ. Geochem. Health 44 (9) (2022) 2975–2986, https://doi.org/10.1007/s10653-021-01146-z.
[21] Defense Contract Audit Agency, Environmental Protection in China in the Past 70 Years, Beautiful China: 70 Years Since 1949 and 70 People's Views on Eco-civilization Construction, 2019, pp. 35–45, https://doi.org/10.1007/978-981-33-6742-5_3.
[22] C. Jasch, The use of Environmental Management Accounting (EMA) for identifying environmental costs, J. Clean. Prod. 11 (2003) 667–676, https://doi.org/10.1016/S0959-6526(02)00107-5.
[23] M.S. Hammer, T.K. Swinburn, R.L. Neitzel, Environmental noise pollution in the United States: developing an effective public health response, Environ. Health Perspect. 122 (2) (2014) 115–119, https://doi.org/10.1289/ehp.1307272.
[24] S. Tanaka, Environmental regulations on air pollution in China and their impact on infant mortality, J. Health Econ. 42 (2015) 90–103, https://doi.org/10.1016/j.jhealeco.2015.02.004.
[25] T. Lihui, G. Xin, L. Zheng, L. Xin, Reform of environmental protection fee-to-tax and enterprise environmental protection investment: a quasi-natural experiment based on the implementation of the environmental protection tax law, J. Finance Econ. 48 (9) (2022 Sep 3) 32–46.
[26] L. Carles, F. Martin-Laurent, M. Devers, A. Spor, N. Rouard, J. Beguet, P. Besse-Hoggan, I. Batisson, Potential of preventive bioremediation to reduce environmental contamination by pesticides in an agricultural context: a case study with the herbicide 2, 4-D, J. Hazard Mater. 416 (2021 Aug 15) 125740.
[27] G. Taglieri, V. Daniele, L. Macera, R. Schweins, S. Zorzi, M. Capron, G. Chaumat, C. Mondelli, Sustainable nanotechnologies for curative and preventive wood deacidification treatments: an eco-friendly and innovative approach, Nanomaterials 10 (9) (2020 Sep 3) 1744.
[28] S. Alkire, J. Foster, Understandings and misunderstandings of multidimensional poverty measurement, J. Econ. Inequal. 9 (2011) 289–314.
[29] D. Lee, G. Shaddick, Spatial modeling of air pollution in studies of its short-term health effects, Biometrics 66 (4) (2010) 1238–1246, https://doi.org/10.1111/j.1541-0420.2009.01376.x.
[30] M. Hosoe, T. Naito, Trans-boundary pollution transmission and regional agglomeration effects, Pap. Reg. Sci. 85 (1) (2006) 99–120, https://doi.org/10.1111/j.1435-5957.2006.00062.x.
[31] H.M. Hosseini, S. Kaneko, Can environmental quality spread through institutions? Energy Pol. 56 (2013) 312–321, https://doi.org/10.1016/j.enpol.2012.12.067.
[32] T. Feng, H. Du, Z. Lin, J. Zuo, Spatial spillover effects of environmental regulations on air pollution: evidence from urban agglomerations in China, J. Environ. Manag. 272 (2020) 110998, https://doi.org/10.1016/j.jenvman.2020.110998.
[33] B. Baybeck, W.D. Berry, D.A. Siegel, A strategic theory of policy diffusion via intergovernmental competition, J. Polit. 73 (1) (2011) 232–247, https://doi.org/10.1017/S0022381610000988.
[34] K. Zhang, D. Xu, S. Li, T. Wu, J. Cheng, Strategic interactions in environmental regulation enforcement: evidence from Chinese cities, Environ. Sci. Pollut. Control Ser. 28 (2021) 1992–2006, https://doi.org/10.1007/s11356-020-10443-6.
[35] T. Hoang, Fiscal competition and state pension reforms, Public Budg. Finance 42 (3) (2022) 41–70, https://doi.org/10.1111/pbaf.12315.
[36] L.P. Tabb, L.A. McClure, H. Quick, J. Purtle, A.V.D. Roux, Assessing the spatial heterogeneity in overall health across the United States using spatial regression methods: the contribution of health factors and county-level demographics, Health Place 51 (2018) 68–77, https://doi.org/10.1016/j.healthplace.2018.02.012.
[37] C. Zhao, B. Wang, How does new-type urbanization affect air pollution? Empirical evidence based on spatial spillover effect and spatial Durbin model, Environ. Int. 165 (2022) 107304, https://doi.org/10.1016/j.envint.2022.107304.

[38] F.T. Dabuo, J. Du, B. Madzikanda, P.T. Coulibaly, Influence of research and development, environmental regulation, and consumption of energy on CO2 emissions in China—novel spatial Durbin model perspective, Environ. Sci. Pollut. Control Ser. 30 (11) (2023) 29065–29085, https://doi.org/10.1007/s11356-022-23647-9.
[39] D. Herrera, A. Ellis, B. Fisher, et al., Upstream watershed condition predicts rural children's health across 35 developing countries, Nat. Commun. 8 (2017) 811, https://doi.org/10.1038/s41467-017-00775-2.
[40] China Family Panel Studies (CFPS). PKU open research data platform. [Data set].Peking University, China. https://opendata.pku.edu.cn/dataverse/CFPS?language=en.
[41] S. Alkire, J. Foster, Counting and multidimensional poverty measurement, J. Publ. Econ. 95 (7–8) (2011) 476–487, https://doi.org/10.1016/j.jpubeco.2010.11.00.
[42] Sabina Alkire, Maria Emma Santos, Acute Multidimensional Poverty: A New Index for Developing Countries, Oxford Poverty & Human Development Initiative (OPHI) Working Paper No. 38, United Nations Development Programme Human Development Report Office Background Paper No. 2010/11, July 1, 2010, https://doi.org/10.2139/ssrn.1815243.
[43] R. Hick, Poverty as capability deprivation: conceptualising and measuring poverty in contemporary europe, Eur. J. Sociol./Arch. Eur. Sociol. 55 (3) (2014) 295–323, https://doi.org/10.1017/S0003975614000150.
[44] R. López, G.I. Galinato, A. Islam, Fiscal spending and the environment: theory and empirics, J. Environ. Econ. Manag. 62 (2) (2011) 180–198, https://doi.org/10.1016/j.jeem.2011.03.001.
[45] V. Koval, O. Laktionova, N. Rogoza, O. Chumak, V. Komandrovska, M. Berdar, The impact of fiscal policy on environmental management in ensuring sustainable economies, in: IOP Conference Series: Earth and Environmental Science, vol 1126, IOP Publishing, 2023 012016, https://doi.org/10.1088/1755-1315/1126/1/012016, 1.
[46] T. Yang, W. Liu, Does air pollution affect public health and health inequality? Empirical evidence from China, J. Clean. Prod. 203 (2018) 43–52, https://doi.org/10.1016/j.jclepro.2018.08.242.
[47] Z. Zhang, G. Zhang, L. Li, The spatial impact of atmospheric environmental policy on public health based on the mediation effect of air pollution in China, Environ. Sci. Pollut. Control Ser. (2022) 1–17, https://doi.org/10.1007/s11356-022-21501-6.
[48] A.L. Goodkind, J.S. Coggins, J.D. Marshall, A spatial model of air pollution: the impact of the concentration-response function, Journal of the Association of Environmental and Resource Economists 1 (4) (2014) 451–479, https://doi.org/10.1086/678985.
[49] B. Sun, B. Wang, Spatial spillover effects of air pollution on the health expenditure of rural residents: based on spatial Durbin model, Int. J. Environ. Res. Publ. Health 18 (13) (2021) 7058, https://doi.org/10.3390/ijerph18137058.
[50] B.H. Baltagi, M.H. Pesaran, Heterogeneity and cross section dependence in panel data models: theory and applications introduction, J. Appl. Econom. 22 (2) (2007) 229–232, https://doi.org/10.1002/jae.955.
[51] M.J. Valente, J.J. Rijnhart, H.L. Smyth, F.B. Muniz, D.P. MacKinnon, Causal mediation programs in R, M plus, SAS, SPSS, and Stata, Struct. Equ. Model.: A Multidiscip. J. 27 (6) (2020) 975–984, https://doi.org/10.1080/10705511.2020.1777133.
[52] D. Chen, M.S. Fritz, Comparing alternative corrections for bias in the bias-corrected bootstrap test of mediation, Eval. Health Prof. 44 (4) (2021) 416–427, https://doi.org/10.1177/01632787211024356.
[53] J. Prochaska, H. Kelley, S. Linder, K. Sexton, J. Sullivan, L. Nolen, Health inequities in environmental justice communities: relevant indicators to reflect a variety of health threats, Int. J. Equity Health 11 (Suppl 1) (2012), https://doi.org/10.1186/1475-9276-11-S1-A7. A7-A7.
[54] Sabina Alkire, Maria Emma Santos, Acute Multidimensional Poverty: A New Index for Developing Countries (July 1, Oxford Poverty & Human Development Initiative, 2010, https://doi.org/10.2139/ssrn.1815243 (OPHI) Working Paper No. 38, United Nations Development Programme Human Development Report Office Background Paper No. 2010/11.
[55] R. Hick, Poverty as capability deprivation: conceptualising and measuring poverty in contemporary Europe, Eur. J. Sociol./Arch. Eur. Sociol. 55 (3) (2014) 295–323, https://doi.org/10.1017/S0003975614000150.