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Relationship between Environmental Pollution, Environmental Regulation and Resident Health in the Urban Agglomeration in the Middle Reaches of Yangtze River, China: Spatial Effect and Regulating Effect

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Abstract: The Healthy China 2030 Initiative is closely related to the coordinated development between national health, economy, and society. This major move demonstrates China's active engagement in global health governance and in the fulfillment of the 2030 Agenda for Sustainable Development (SDGs). Based on Grossman's health production function, this paper introduces key factors such as environmental pollution and environmental regulation to empirically investigate the regulating effect of environmental regulation, as well as the spatial spillover of environmental pollution and environmental regulation acting on resident health. We examine these effects by using the panel data of 28 cities of the urban agglomeration in the middle reaches of the Yangtze River (UAMYRY) between 2009 and 2019. The results show that: (1) Environmental pollution brings a loss to resident health. Among the urban agglomerations, the circum-Changsha–Zhuzhou–Xiangtan urban agglomeration (CCZXUA) and the Poyang Lake urban agglomeration (PLUA) have a much lower health effect of environmental pollution than the Wuhan urban agglomeration (WUA). (2) With the growing intensity of environmental regulation, the negative effect of environmental pollution on resident health will gradually decrease. Regionally, the environmental regulation in the CCZXUA has the best effect on residents' health, followed by the WUA and the PLUA, which have the worst. (3) As a whole, the spatial spillover of environmental regulation and pollution has a significant impact on residents' health, and the spatial spillover effect between urban agglomerations is stronger than that between cities in each urban agglomeration. The conclusions remain robust with various tests such as replacing control variables, introducing lagged explanatory variables, and considering endogeneity. Based on robust empirical evidence, several specific region policy suggestions, including rolling out proper environmental regulation policies, and establishing a linking mechanism of environmental management, were put forward to improve the environmental pollution state and resident health level of the UAMYRY.

Keywords: resident health; environmental regulation; environmental pollution; carbon peaking and carbon neutrality goals; spatial Durbin model

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1. Introduction

Global warming and climate change appear world-challenging problems where the Paris accord lays great stress to resolve with global efforts. Indeed, the global issues of climate change and environmental pollution impede the pursuit of green and sustainable economic development, cause huge health costs to many countries, and even present an existential threat to society. According to the World Bank and the World Health Organization, 70% of diseases and 40% of deaths around the world are attributable to environmental factors. Air pollutants such as SO_2, NO_2, and soot can cause the frequent occurrence of many chronic conditions, such as lung cancer and cardiovascular and cerebrovascular diseases [1,2]. The Chinese government has given great importance to environmental pollution and resident health, considering their serious concerns for the population. In 2020, China made a solemn promise to the world: the country will adopt more favorable measures to peak its CO_2 emissions by 2030 and realize carbon neutrality by 2060. To achieve this national strategic goal, local governments work coordinately to promote pollution control and emission reduction.

Taking up about 20% of China's landmass, the Yangtze River Economic Belt (YREB) contributes nearly 45% of the total economic output and supports more than 40% of the country's population. In 2020, the YREB discharged more than 40% of wastewater, emitted 36.6% of SO_2, released 45.4% of NO_x, and produced 28.4% of particulate matter (China Statistical Yearbook 2021, URL: http://www.stats.gov.cn/tjsj/ndsj/, accessed on 5 January 2022). On 14 November 2020, the Chinese President hosted a symposium on promoting the development of the YREB where he stressed that: On the premise of strictly protecting the ecological environment, it is important to realize efficient resource utilization, accelerate the promotion of green and low-carbon development, and strive to build a green development that demonstrates belt for the harmonious coexistence between human and nature. Strengthening environmental regulation becomes an inevitable means for the YREB to achieve sustainable development. However, the independent pollution control by local governments is far from enough to handle the regional spatial spillover effect of environmental pollution. In order to realize cross-regional collaborative governance of environmental pollution, urban agglomerations could be taken as effective spatial units for their compact spatial organization, close economic ties, and high integration. Therefore, this paper focuses on the urban agglomeration in the middle reaches of the Yangtze River (UAMYRY), the first super-large state-level urban agglomeration approved in China. The UAMYRY leads the implementation of China's major regional strategies and regional integrated development. An objective and scientific evaluation of the environmental effects of UAMYRY's environmental regulation policies is conductive to formulate highly feasible policies for cross-city linkage and regional control. The evaluation results would provide a reference for the UAMYRY to construct an ecological civilization, develop a green, low-carbon development model for the region, and offer precious experience for China to smoothly realize its carbon peaking and carbon neutrality goals.

The existing research on environmental pollution, environmental regulation, and resident health can be divided into two categories: the relationship between environmental pollution and resident health; the effectiveness of environmental regulation. Focusing on the problem of environmental pollution and resident health, the first category of studies covers such fields as medicine, health geography, environmental epidemiology, and environmental economics and mainly adopts analytical methods and statistical models. Based on the principle of dose–effect and exposure–response, the analytical methods primarily analyze the loss of resident health caused by environmental pollution. These methods generally hold that environmental pollution affects resident health via exposure–response coefficient, pollutant concentration, and exposed urban population. Moreover, the SO_2, NO_2, and inhalable particulate matter (PM2.5 and PM10) in the air bring various adverse human impacts, such as cardiovascular illnesses, respiratory illnesses, and lung problems [3–6]. Statistical models mainly examine the correlations between environmental indices (e.g., water quality level and pollutant concentration) and health indices (prevalence and mortality of relevant diseases) or statistically test the correlations [7,8]. Some scholars adopted relatively complex econometric models to analyze the effects of environmental pollution on resident health [9,10]. The second category of studies emphasizes the effectiveness of environmental regulation. Most scholars agree that environmental regulation policies effectively decrease the emissions of pollutants and improve environmental quality [11,12]. However, some scholars pointed out that the status quo of environmental pollution cannot be improved by environmental regulation policies [13,14]. In addition, environmental regulation policies indirectly affect resident health. Environmental regulation may not directly affect the level of resident health. Taking environmental pollution as the mediating variable, some researchers have discovered that environmental regulation policy can alleviate the negative externality of environmental pollution, thereby improving the level of resident health [15,16]. Some other researchers found that environmental regulation may indirectly affect residents' subjective well-being by shaping their subjective perception of environmental conditions and thus, improve residents' health conditions [17].

In summary, the existing research concentrates on the health problems brought by pollution and the policy effects of environmental regulation and rarely talks about the internal correlations between these issues. Neither did they consider how the spillover features of environmental pollution and environmental regulation affect resident health. In addition, the predecessors studied state- or provincial-level subjects and overlooked the difference in economic structure between cities, making it impossible to prepare pertinent policies for environmental regulation. Unlike the existing research, this paper has several innovative points: (1) Starting from the regulating effect of environmental regulation, the paper deeply discusses the interaction between environmental regulation, environmental pollution, and resident health in UAMYRY. (2) Drawing on the spillover features of environmental pollution and environmental regulation, the paper probed deep into how the spatial spillover of these two factors acts on resident health. (3) The sample space was extended to the regional level, with urban agglomerations as the units, and the urban heterogeneity and regional integrity were both considered, shedding light on how to formulate coordinated regional policies for environmental regulation according to local conditions.

2. Theoretical Framework and Hypotheses

2.1. Environmental Pollution and Resident Health

The theoretical research on the relationship between environmental pollution and resident health can be traced back to the health production function proposed by Grossman in 1972, which views the current health stock as a function of health investment and health depreciation [18]. Cui et al. (2016) believed that environmental pollution directly or indirectly damages human health, weakens human functions, increases the cost of resident health to a certain extent, and accelerates health depreciation [19]. The growing level of environmental pollution would add to health depreciation and lower the health stock. Following the law of diminishing marginal utility, when the health stock decreases, the utility of increasing one unit of health expenditure is greater than that of adding one unit of other normal commodity consumption. Based on the principle of utility maximization, the deepening of environmental pollution will bring additional health costs, crowd out other physical capital investments, and in turn, negatively affects social welfare. The traditional epidemiological views agree that the toxic industrial wastewater, waste gas, and waste residue, as well as the productive poisons in chemical factors, could pollute the environment in the form of gas, mist, smoke, or dust. These toxic substances may enter the human body, causing peripheral neuritis, Minamata disease, and chronic organochlorine poisoning. The intake of these substances would also increase the incidence of diseases such as common cold, asthma, and chronic bronchitis. Hence, the following hypothesis was put forward:

Hypothesis 1. *Environmental pollution accelerates health depreciation and significantly suppresses resident health.*

2.2. The Regulating Effect of Environmental Regulation

The following three levels are used to explore the ways in which environmental regulation plays a regulatory role: (1) Enterprise level. For one thing, environmental regulation squeezes the productive investment of enterprises. Thus, the funds originally used for research and development (R&D) and innovation are diverted to the non-productive link of environmental governance. In this way, environmental regulation improves the environmental quality of the entire society. For another, the pollution control cost induced by environmental regulation can stimulate technological innovation of enterprises, which would compensate for the cost of compliance. This would enable enterprises to reduce costs and increase efficiency in the process of pollution control and emission reduction. (2) Industry level. Environmental regulation puts higher requirements on the management mode, technical level, cost budget, and pollution control effect of market players. Only the fittest industries and enterprises could survive environmental regulation. When heavy polluting industries have a strong binding force and influence, and the environmental regulation is intense, market players tend to choose the industries that are less constrained by environmental regulation. Thus, the service industry will take up a greater proportion of the industrial structure. That is, environmental regulation would reshape the industrial structure. (3) Social level. The government guides the public to participate in environmental governance by introducing and implementing environmental regulation policies and carrying out environmental education and knowledge lectures. The public, as the most direct perceivers of the local environmental quality, can efficiently and sustainably participate in the real-time governance of the local environment. With the growing awareness of the importance of the environment to the quality of life, the public will gradually establish and strengthen their awareness of environmental protection and health. Overall, environmental regulation can moderate the regional situation of environmental pollution through the response of enterprises, industries, and society. The improvement of environmental pollution will, in turn, promote resident health. Hence, the following hypothesis was put forward:

Hypothesis 2. *Environmental regulation positively regulates the relationship between environmental pollution and resident health.*

2.3. The Spatial Spillover of Environmental Pollution and Environmental Regulation

Environmental pollution is a harmful substance with strong spillover features that transcends geographical boundaries. Because of the spillover effect, environmental pollution could break the limitation of space and diffuse and spread via the air, rivers, and biological media, posing a serious threat to resident health in the local and surrounding cities of the pollution source. In addition, the spillover of environmental pollution and the transfer of polluting enterprises across cities make it impossible for the cities that implement environmental regulation to obtain all the benefits of their regulation. The spillover mechanism is mainly reflected in the following aspects: First, local governments have a strategic interaction in environmental regulation. The environmental regulation intensity of the local city could be affected by that of surrounding cities. The environmental pollution level of the local city is thus determined. Second, the governance effect brought by environmental regulation in surrounding cities will influence the level of environmental pollution in the local city through the spillover of environmental pollution. Third, the different cities implement environmental regulations at different intensities. This difference may cause production factors to flow between cities. As a result, the polluting enterprises that cannot adapt to strict environmental regulations may relocate to nearby cities. The relocation would hinder the environmental pollution of these cities. That means, on the one hand, residents' health is influenced by their own urban environmental regulations and environmental pollution; on the other hand, residents' health is also constrained by environmental pollution and environmental regulations in neighboring areas. Hence, the following hypothesis was put forward:

Hypothesis 3. *Environmental pollution and environmental regulation have spatial spillover effects, and they have certain impacts on residents' health.*

3. Model Construction and Data Processing

3.1. Model Construction

From a microscopic perspective, Grossman (1972) constructed the model of health demand and health production function [18], laying the theoretical basis for health economics. According to the actual situation in China, Zhao (2006) [20] and Lu and Qi (2013) [21] incorporated factors such as economy, society, education, and health care to formulate a macroscopic health production function. Referring to previous studies, the paper sets up the following macroscopic model for health production function:

$$lnDR_{it} = \beta_0 lnEP_{it} + \boldsymbol{X}_{it}{}'\boldsymbol{\phi} + \alpha_i + \varepsilon_{it} \tag{1}$$

where, subscripts i and t are the number of cities and years, respectively; $lnDR_{it}$ is the level of resident health; β_0 is the coefficient of environmental pollution; $lnER_{it}$ is the level of environmental pollution; $\boldsymbol{X}_{it}{}'$ is the matrix of control variables; $\boldsymbol{\phi}$ is the coefficient vector of control vectors; α_i is individual fixed effects; ε_{it} is a random disturbance.

Based on model (1), the cross term of environmental pollution and environmental regulation ($ER_{it} \times lnEP_{it}$) was introduced to test the influence of environmental pollution on residents' health under different degrees of environmental regulation while controlling the factors of environmental pollution and environmental regulation. The regulating effect model can be established as:

$$lnDR_{it} = \beta_1 ER_{it} \times lnEP_{it} + \beta_2 ER_{it} + \beta_0 lnEP_{it} + \boldsymbol{X}_{it}{}'\boldsymbol{\phi} + \alpha_i + \varepsilon_{it} \tag{2}$$

where, β_1 is the coefficient of cross term between environmental pollution and environmental regulation; ER_{it} is the level of environmental regulation; β_2 is the coefficient of environmental regulation.

The following spatial Durbin model was constructed based on model (1) to recognize the influence of environmental pollution level and environmental regulation intensity of surrounding cities over the resident health of the local city:

$$lnDR_{it} = \rho \boldsymbol{W} lnDR_{it} + \beta_0 lnEP_{it} + \lambda \boldsymbol{W} lnEP_{it} + \boldsymbol{X}_{it}{}'\boldsymbol{\phi} + \boldsymbol{W}\boldsymbol{X}_{it}{}'\boldsymbol{\psi} + \varepsilon_{it} \tag{3}$$

where, $\boldsymbol{W}$ is the spatial weight matrix; $\boldsymbol{W}lnDR_{it}$, $\boldsymbol{W}lnEP_{it}$, and $\boldsymbol{W}\boldsymbol{X}_{it}{}'$ are the spatial lag terms of explained variable, explanatory variable, and control variables, respectively; ρ, λ, and $\boldsymbol{\psi}$ are the coefficient vectors of the spatial lag terms of the explained variable, explanatory variable, and control variables, respectively.

3.2. Variable Selection

3.2.1. Explained Variable: Resident Health

In microscopic studies, questionnaires are often used to obtain respondents' subjective perception of health state, which characterizes the level of resident health. The relevant indices help to judge various information, including disease severity and health stability, and comprehensively reflect individual health states. However, the subjective state of respondents may easily affect the objectivity and accuracy of the results. Indeed, it is very difficult to measure the health state of all residents in a certain region. The common practice is to measure the resident health level with a relative or mean index. The indices generally used to describe public health conditions are mortality, average life expectancy, etc. In the light of the data availability and referring to Qi and Lu (2015) [22] and Ruan et al. (2020) [23], this paper selects mortality to characterize resident health state. Mortality is taken as the primary health index in the Outline of the Healthy China 2030 Plan, which pledges to reduce the mortality of children under 5 to 6‰ and decrease the premature mortality from major chronic diseases by 30%, compared with that in 2015, by 2030. Mortality is a negative index, i.e., the higher the mortality, and lower the level of resident health.

3.2.2. Core Explanatory Variable: Environmental Pollution

There are two main data sources of China's environmental pollution indices. One is the monitoring data of urban pollutant concentrations. For example, the monitoring data on the air pollutant concentrations in 113 key cities. Initially, the monitoring objects include SO_2, total air suspension (TAS), and NO_X. In 2003, the objects were changed into SO_2, PM10, and NO_2. The other is the data on the discharge of industrial pollutants, such as the data on the discharge of industrial wastewater, industrial waste gas, and industrial solid waste released by each province. Due to data availability, most scholars choose to analyze the provincial or city panel data on industrial pollutant emissions [24,25]. Thus, this paper selects several indices, namely, urban CO_2 emissions, industrial wastewater emissions, industrial SO_2 emissions, and industrial soot emissions, and synthesizes them into a composite index for environmental pollution by the entropy weight method. The composite index characterizes the degree of environmental pollution.

3.2.3. Regulated Variable: Environmental Regulation

The representative indices of environmental regulation include the per-capita gross regional product (GRP), the number of environmental regulation policies and regulations, the proportion of investment in environmental pollution governance, and the pollution governance compliance rate. From the perspective of the control effect of environmental pollution, this paper draws on the study of Yue and Xue (2020) [26] and Huang and Wu (2021) [27], selects such three indices as the comprehensive utilization rate of industrial solid waste, the centralized treatment rate of sewage treatment plants, and harmless treatment rate of household waste, and processes them by the entropy weight method to evaluate the level of environmental regulation.

3.2.4. Control Variables

According to our macroscopic model for health production function, the economic, medical, educational, and social factors that affect resident health were introduced as the main control variables. The economic factor was represented by per-capita gross domestic product (GDP). A high economic output leads to the provision of high-quality goods and services and better housing and medical conditions, resulting in an improved health state. The medical and health level was represented by the number of certified (assistant) doctors per 1000 people. In general, the greater the number, the higher the level of health facilities. Education has a crucial impact on quality of life (e.g., job opportunities, ability to obtain nutrition, willpower to avoid unhealthy lifestyles, and use efficiency of medicines). Here, the educational factor was measured by the number of university students per 10,000 people. The social factor was represented by the urbanization rate and the number of patent authorizations. The level of science and technology and the degree of urbanization development affect the quality of medical information and medical services, and urban medical services are more efficient than rural medical services. The names, symbols, and meanings of each variable are displayed in Table 1.

3.3. Study Area and Data Explanation

3.3.1. Study Area

This paper empirically analyzes the panel data of the 28 cities in the UAMYRY for the period from 2009 to 2019. The UAMYRY is an integral part of the YREB and the key to the realization of the Rise of Central China Strategy. According to the Outline for the UAMYRY Development released in 2015, the UAMYRY covers 31 cities in the circum-Changsha–Zhuzhou–Xiangtan urban agglomeration (CCZXUA), Wuhan urban agglomeration (WUA), and the Poyang Lake urban agglomeration (PLUA). Specifically, the CCZXUA includes eight cities in Hunan Province, namely, includes Changsha, Zhuzhou, Hengyang, Xiangtan, Yiyang, Changde, Yueyang, and Loudi. The WUA includes thirteen cities in Hubei Province, namely, Wuhan, Huangshi, Yichang, Xiangyang, Jingmen, Ezhou, Xiaogan, Jingzhou, Huanggang, Xianning, Xiantao, Tianmen, and Qianjiang. Note that

Xiantao, Qianjiang, and Tianmen were excluded from the sample set owing to a serious lack of data. The PLUA includes ten cities in Jiangxi Province, namely, Nanchang, Jiujiang, Jingdezhen, Yingtan, Shangrao, Fuzhou, Xinyu, Yichun, Pingxiang, and Ji'an.

Table 1. Variable description.

Variables	Names	Units	Symbols	Definitions
Explained variable	Mortality	‰	*DR*	Reflect the health status of resident
Core explanatory variable	Environmental pollution	-	*EP*	Reflect the degree of environmental pollution
Regulated variable	Environmental regulation	-	*ER*	Reflect the intensity of environmental regulation
Control variables	Per-capita gross domestic product	Ten thousand Yuan	*RGDP*	Reflect the level of economic development
	Number of certified (assistant) doctors per 1000 people	People	*HC*	Reflect the level of medical and health
	Number of university students per 10,000 people	People	*ED*	Reflect the educational level of the population
	Urbanization rate	%	*UB*	Reflect the level of urban development
	Number of patent authorizations	One hundred Pieces	*PL*	Reflect the level of science and technology

3.3.2. Data Source

As China does not release official data for urban carbon emissions, this paper estimates urban carbon emissions by the calculation method generally adopted by predecessors: Most scholars compute carbon emissions based on energy consumption data, for carbon emissions mainly come from energy consumption activities [28–30]. Drawing on the algorithm of Zhang and Cui (2018) [31], the carbon emissions from terminal energy consumption (by industry) of each province were first calculated from the energy balance sheet (physical quantity) of each province. Next, the carbon emissions of different industries, including agriculture, forestry, animal husbandry, and fishery, manufacturing industry, construction, transportation, storage and postal industry, wholesale and retail industry, accommodation and catering industry, and other service industries, were allocated to each city in each province, according to the output of each industry in each city as a percentage of the output of that industry in the local province. Finally, the carbon emissions of industries in a city were added up to obtain the total carbon emissions of that city. The provincial carbon emissions (by industry) can be calculated as:

$$CO_2 = \sum_{p=1}^{8} E_{pj} \times NCV_p \times CEF_p \times COF_p \times (44/12) \tag{4}$$

where, CO_2 is the total CO_2 emissions of a province (by industry); E_{pj} is the final consumption of energy p in industry j; NCV_p is the mean net calorific value of each energy (NCV); CEF_p is the carbon emission factor (CEF); COF_p is the carbon oxidation factor (COF); 44/12 is the gasification coefficient of CO_2. Note that industry j was classified by the terminal energy consumption catalog in China Energy Statistical Yearbooks. The residents' domestic energy consumption was not calculated because the consumption is too small, and no province has published any data about the added value of residents' living. Drawing on China Energy Statistical Yearbooks, the energy consumption p was eventually divided into coal, coke, petroleum, gasoline, kerosene, diesel, fuel oil, natural gas, and electrical power. For two reasons, electricity consumption was not considered: electricity is generated by consuming other energies, and the CEF of electricity is zero.

The data about terminal energy consumption, the energy conversion factor of standard coal, and NCV were all obtained from China Energy Statistical Yearbooks 2010–2020. The CEF and COF data were extracted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Social and economic data such as residents' health were acquired from China City Statistical Yearbooks 2010–2020, provincial statistical yearbooks, provincial statistical bulletins on social and economic development, and China Stock Market & Accounting Research (CSMAR) Database. Some missing data were supplemented by the arithmetic mean method or sliding window method. The GDP data were deflated by the price index, with 2009 as the base period.

3.3.3. Descriptive Statistics of Variables

The variable data characteristics (sample size, average, standard deviation, minimum, and maximum) used in this paper are reported in Table 2. The statistical objects include the entire sample area of the UAMYRY, as well as three sub-sample areas, the CCZXUA, the WUA, and the PLUA. The descriptive statistical results of variables show that, overall, the statistical characteristics of each variable have significant regional differences, as shown below:

Table 2. Descriptive statistics of variables in various regions.

Variables	The Full Sample					The Circum-Changsha–Zhuzhou–Xiangtan Urban Agglomeration				
	Obs	**Mean**	**Sd**	**Min**	**Max**	**Obs**	**Mean**	**Sd**	**Min**	**Max**
DR	308	0.62	0.15	0.07	1.34	88	0.72	0.07	0.42	0.85
EP	308	0.32	0.18	0.02	0.95	88	0.34	0.14	0.05	0.63
ER	308	0.75	0.18	0.16	1.00	88	0.80	0.15	0.31	0.99
RGDP	308	3.51	1.96	0.99	11.54	88	3.74	2.09	1.26	10.52
HC	308	2.01	0.72	0.81	4.86	88	2.26	0.74	1.09	4.40
ED	308	217.03	292.02	24.86	1176.28	88	243.57	260.93	54.62	965.05
UB	308	53.64	11.30	21.83	80.49	88	53.16	10.47	34.97	79.56
PL	308	25.85	46.58	1.07	391.26	88	29.75	42.51	2.28	225.04
Variables	**The Wuhan Urban Agglomeration**					**The Poyang Lake Urban Agglomeration**				
	Obs	**Mean**	**Sd**	**Min**	**Max**	**Obs**	**Mean**	**Sd**	**Min**	**Max**
DR	110	0.57	0.22	0.07	1.34	110	0.61	0.01	0.55	0.63
EP	110	0.31	0.22	0.04	0.95	110	0.30	0.17	0.02	0.70
ER	110	0.68	0.19	0.16	0.96	110	0.79	0.16	0.35	1.00
RGDP	110	3.83	2.19	0.99	11.54	110	3.01	1.46	1.00	6.81
HC	110	2.12	0.78	0.94	4.86	110	1.70	0.51	0.81	3.56
ED	110	210.62	309.69	41.05	1175.57	110	202.21	298.50	24.86	1176.28
UB	110	53.24	12.39	21.83	80.49	110	54.43	10.84	35.52	75.14
PL	110	30.83	63.40	1.33	391.26	110	17.74	23.35	1.07	130.57

To begin with, the explained variables (DR) differ in different regions and within them, with the greatest variation occurring within the Wuhan metropolitan area. In terms of average annual mortality rates, the CCZXUA has the highest, followed by the PLUA, and the WUA has the lowest. Second, the environmental pollution (EP) in explanatory variables relatively differs in different regions, and the environmental pollution in the CCZXUA is the most serious, followed by the WUA, and the PLUA is relatively light. The difference in environmental regulation (ER) in different regions is relatively small, among which the CCZXUA is the strongest, the PLUA is the second, and the WUA is the lowest. Finally, the annual maximum values of the number of certified (assistant) doctors per 1000 people (HC) and the number of university students per 10,000 people (ED) in the control variables are in the CCZXUA, and the annual maximum values of the per-capita gross domestic product level ($RGDP$) and the number of patent authorizations (PL) are in WUA, while the annual maximum values of urbanization rate (UB) are in the PLUA.

4. Empirical Results

4.1. Health Effect of Environmental Pollution

Before empirical analysis, all variables were logarithmically processed to reduce the effect of heteroskedasticity. In the regulating effect model, the environmental pollution and environmental regulation variables were decentralized to eliminate the influence of multicollinearity. As a result, some data on environmental regulation are negative, so they are no longer logarithmic. Without considering the spatial spillover effect, the regression results on the influence of environmental pollution on resident health are reported in Columns (1)–(4) of Table 3. To avoid estimation bias in the model setting, Columns (1)–(2) also report the results of the mixed regression model, which provides a reference frame for model (1) (the macro model for health production function). The results show that, when all the other conditions remained unchanged, the coefficient of environmental pollution was statistically significant at a 5% level of significance. Hence, environmental pollution is a major influencing factor of resident health levels. Considering the difference between UAMYRY cities, the fixed-effects regression models were introduced after the Hausman test (The p-value was less than 0.01). According to the results in Columns (3)–(4), under the fixed-effects models, the environmental pollution negatively affected resident health at least on the significance level of 10%, whether control variables were added. Hence, hypothesis one was verified: environmental pollution indeed suppresses resident health.

Table 3. Influence of environmental pollution over resident health.

Variables	Mixed Regression Model		Fixed-Effects Regression Model		
	(1)	(2)	(3)	(4)	(5)
$lnEP$	0.0389 ** (0.0168)	0.0473 *** (0.0174)	0.0248 * (0.0140)	0.0289 ** (0.0145)	0.0706 ** (0.0343)
$lnEP \times CCZXUA$					−0.0781 * (0.0412)
$lnEP \times PLUA$					−0.0620 * (0.0356)
$lnRGDP$		0.0143 (0.0401)		0.0652 * (0.0383)	0.0710 * (0.0388)
$lnUB$		−0.0210 (0.0551)		−0.0085 (0.0596)	−0.0312 (0.0618)
$lnPL$		0.0393 *** (0.0114)		0.0235 *** (0.0083)	0.0225 *** (0.0085)
$lnED$		−0.0086 (0.0158)		−0.0126 (0.0118)	−0.0127 (0.0116)
$lnHC$		−0.0194 (0.0525)		−0.0796 ** (0.0340)	−0.0945 *** (0.0356)
Constant	−0.8567 *** (0.1568)	−1.2232 *** (0.3454)	−0.5762 *** (0.1340)	−1.3096 *** (0.3041)	−0.9194 *** (0.3282)
Observation	308	308	308	308	308
R^2	0.0173	0.0739	0.3665	0.3978	0.4096

Note: The results were obtained by Stata 16. The robust standard errors are in parenthesis; *, **, and *** are statistical significance at the 10%, 5%, and 1% levels, respectively. The same below tables.

The urban agglomerations within the UAMYRY have large spatial differences in terms of geographical location, socioeconomic conditions, and technological level. As a result, the health effect of environmental pollution may vary from region to region. To consider this, the paper sets up regional dummy variables for the CCZXUA ($CCZXUA$) and the PLUA ($PLUA$). In addition, the cross terms ($lnEP \times CCZXUA$ and $lnEP \times PLUA$) between regional dummy variables and the core explanatory variable (environmental pollution) were introduced, and the fixed-effects models were employed to further investigate regional differences in the influence of environmental pollution on resident health in the urban agglomerations within the UAMYRY. In Table 3, Column (5), it is shown that the coefficients of the cross terms between the CCZXUA and the PLUA and environmental pollution were both significantly negative, indicating that the negative impact of environmental pollution on resident health in the two regions is much smaller than that in the WUA. The possible reason is that the manufacturing and service industries in the WUA are slightly more developed than those in the CCZXUA and the PLUA. Moreover, Wuhan, the central city of the WUA, boasts a relatively high opening degree, the most foreign-funded financial institutions in Central China, and a relatively high level of economic development, but the government less attention to the environment. That is why the negative impact of environmental pollution on resident health in the WUA is the most significant among the three urban agglomerations within the UAMYRY.

4.2. Regulating Effect of Environmental Regulation

Model (2) (regulating effect model) was subjected to regression analysis to test whether the variation in environmental regulation intensity affects the health effect of environmental pollution, i.e., whether environmental regulation can adjust the relationship between environmental pollution and resident health. According to the results in Columns (1)–(2), Table 4, the coefficient of the cross term between environmental pollution and environmental regulation was significantly negative, passing the significance test at the level of 5%. The coefficient of environmental pollution was significantly positive at the 10% level. After adding control variables, the values of both coefficients have increased. Thus, environmental regulation has a significant negative regulating effect: it suppresses the negative impact of environmental pollution on resident health and alleviates the harm caused by environmental pollution to resident health. The regression results in Columns (1)–(2) also indicate that the coefficient of environmental regulation was significantly positive, revealing the obvious substitutive relation between environmental pollution and environmental regulation in the influence over resident health levels. When environmental regulation is weak, environmental pollution has an apparent impact on resident health. With the growing intensity of environmental regulation, the negative impact of environmental pollution on resident health gradually declined. Hence, hypothesis two was verified: environmental regulation weakens the negative impact of environmental pollution on resident health.

In addition, the environmental regulation was divided into two levels, namely, relatively high (above the annual mean, denoted as 1) and relatively low (below the annual mean, denoted as 0), referring to the annual mean intensity of environmental regulation in each city during 2009–2019. Then, the above conclusions were further verified by the fixed-effects model, using the cross term ($lnEP \times SER$) between the dummy variable of environmental regulation intensity (SER) and the core explanatory variable (environmental pollution). The results in Column (3), Table 4 suggest that the cross term ($lnEP \times SER$) between the dummy variable of environmental regulation intensity and environmental pollution was significantly negative, passing the significance test at a 5% level. Thus, the health effect of environmental pollution varies significantly with the changes in the intensity of environmental regulation. In a city with intense environmental regulation, the improvement of resident health is relatively apparent. These findings are basically consistent with the above conclusions.

Columns (4) to (6) of Table 4 further report the sub-sample regression results of the regulating effect of environmental regulation on residents' health. It can be seen from the table that the cross-term values of environmental regulation and environmental pollution in the three urban agglomerations are significantly negative, which indicates that the environmental regulation in each sub-urban agglomeration has a significant positive regulatory effect on residents' health. By comparing the absolute value of its coefficient, the CCZXUA is the largest (−0.32), followed by WUA (−0.0757), and PLUA is the smallest (−0.0158). This shows that the environmental regulation in CCZXUA has the best regulating effect on residents' health, which may be because of the fact that the government in CCZXUA considers the environment seriously (the annual average of its environmental regulation intensity is the largest). From the above conclusion, the regulation effect of environmental regulation in areas with stronger environmental regulation is better.

Table 4. The regulating effect of environmental regulation on the residents' health by region.

Variables	The Full Sample			The Circum −Changsha −Zhuzhou− Xiangtan Urban Agglomeration	The Wuhan Urban Agglomeration	The Poyang Lake Urban Agglomeration
	(1)	(2)	(3)	(4)	(5)	(6)
$lnEP$	0.0269 *	0.0322 **	0.0671 ***	0.2510	−0.0151	0.0224 ***
	(0.0141)	(0.0150)	(0.0259)	(0.1410)	(0.0590)	(0.0036)
$lnEP \times ER$	−0.2281 **	−0.2475 **		−0.3200 *	−0.0757 ***	−0.0158 *
	(0.1021)	(0.1062)		(0.1520)	(0.0176)	(0.0084)
ER	2.1815 **	2.3163 **		3.1930 *	1.2870 ***	−0.0206
	(0.9624)	(1.0074)		(1.5140)	(0.2800)	(0.0220)
$lnEP \times SER$			−0.0682 **			
			(0.0306)			
$lnRGDP$		0.0665 *	0.0593	0.0909	0.1310	0.0803 **
		(0.0377)	(0.0392)	(0.1120)	(0.1610)	(0.0310)
$lnUB$		−0.0320	−0.0281	−0.3640	−0.1520	−0.0736
		(0.0570)	(0.0589)	(0.4300)	(0.1010)	(0.0700)
$lnPL$		0.0242 ***	0.0265 ***	0.0092	−0.0038	−0.0071
		(0.0085)	(0.0083)	(0.0269)	(0.0672)	(0.0057)
$lnED$		−0.0095	−0.0128	0.0545	−0.0337	−0.0009
		(0.0116)	(0.0117)	(0.1990)	(0.1140)	(0.0165)
$lnHC$		−0.0779 **	−0.0830 **	−0.0885	−0.0426	0.0033
		(0.0331)	(0.0342)	(0.0638)	(0.0717)	(0.0097)
Constant	−0.5999 ***	−1.2861 ***	−1.5754 ***	−2.6370	−2.1890	−1.1840 ***
	(0.1350)	(0.3168)	(0.3764)	(1.4630)	(2.0320)	(0.2190)
Observation	308	308	308	88	110	110
R^2	0.3861	0.4160	0.4201	0.2237	0.0958	0.3091

4.3. Spatial Spillover Effect of Environmental Pollution and Environmental Regulation

There are three different spatial econometric models, namely, the spatial lag model (SLM), spatial Durbin model (SDM), and spatial error model (SEM). Which model to choose depends on the results of the Lagrange Multiplier (LM) test. The results of the LM test showed that both LM statistics and Robust LM statistics in SLM and SEM had passed the significance test at the 1% level, which indicates the existence of spatial errors and spatial lag effects. Therefore, SDM was selected for further analysis. Further, the likelihood ratio (LR) test and the Wald test discovered that both SLM and SEM had passed the significance test at the 5% level, which indicates SDM cannot be simplified to SLM or SEM (Please see Table A1 in Appendix A for adaptability test results of spatial metrology model). Table 5 presents the empirical results calculated by the SDM. As mentioned in Column (1), the result of the spatial lag estimation coefficient of environmental pollution showed that environmental pollution in surrounding cities has a significant negative effect on the resident health level of the local city. This confirms the negative externality features of environmental pollution. The spatial lag coefficient of environmental regulation was significantly negative, indicating that the intensity of environmental regulation in surrounding cities significantly promotes the resident health level of the local city.

LeSage and Pace (2009) held that, even if the variables have statistically significant estimated coefficients, the spatial spillover effect of environmental pollution and environmental regulation cannot be judged on this basis [32]. Following this train of thought, we computed the direct effect, indirect effect, and total effect of environmental pollution and environmental regulation, aiming to prevent wrong conclusions from incorrect point estimation. The results are displayed in Columns (2)–(4). Note that the direct effect represents the influence of environmental pollution and environmental regulation in the local city over resident health in that city; the indirect effect represents the influence of environmental pollution and environmental regulation in surrounding cities over resident health in the local city; the total effect can be obtained by adding up direct effect with an indirect effect.

Table 5. Influence of spatial spillover effect of environmental pollution and environmental regulation over resident health.

Variables	(1) Estimation Coefficient	(2) Direct Effect	(3) Indirect Effect	(4) Total Effect
$lnEP$		0.0447 ** (0.0223)	0.5379 *** (0.1577)	0.5825 *** (0.1696)
$lnER$		−0.0909 (0.0555)	−1.1402 *** (0.3522)	−1.2312 *** (0.3742)
$\boldsymbol{W}lnEP$	0.3194 *** (0.0899)			
$\boldsymbol{W}lnER$	−0.6900 *** (0.1967)			
$\boldsymbol{W}lnDR$	0.4031 *** (0.1022)			
Control variables	Yes	Yes	Yes	Yes
Observation	308	308	308	308
R^2	0.0300	0.0300	0.0300	0.0300

4.3.1. Decomposing the Spatial Effect of Environmental Pollution

As shown in Columns (2)–(4), Table 5, the direct effect coefficient (0.0447) and indirect effect coefficient (0.5379) of environmental pollution were significantly positive. This means the environmental pollution levels of the local city and the surrounding cities both significantly suppress resident health in the local city. The negative impact from the surrounding cities was more significant than that from the local city. The reason is that the UAMYRY environmental pollution mainly comes from industrial emissions. Industrial pollution is unbounded by nature. Thus, the industrial pollutants often spread to neighboring cities, resulting in a negative spillover effect. The resident health is damaged after long-term exposure to air and water pollutants. Further, the direct effect of environmental pollution was compared with the estimation coefficient (0.3194) of environmental pollution in Column (1). Since the non-spatial model ignores the spillover of pollutants, the negative impact of environmental pollution in surrounding cities on the resident health of the local city was unilaterally reflected as the health effect of environmental pollution in that city. Hence, the coefficient of environmental pollution in the local city was overestimated.

4.3.2. Decomposing the Spatial Effect of Environmental Regulation

The direct and indirect effect coefficient of environmental regulation were −0.0909 and −1.1402, respectively, and the latter passed the significance test at 1%. Therefore, the level of resident health in the local city is promoted simultaneously by the environmental regulation intensities of the local city and of the surrounding cities. The promoting effect from the surrounding cities was more prominent than that from the local city. The fundamental cause is the continuous growth of the UAMYRY's investment in industrial pollution control during the research period. In 2019, this investment reached RMB3.899 billion, growing at an annual mean rate of 3.9%. These data were computed based on the figures in 2010–2020 China Statistical Yearbooks (http://www.stats.gov.cn/tjsj/ndsj/, accessed on 4 March 2022). This means the governments in the study area have given great importance to ecological environment governance and utilize the funds for environmental governance efficiently. The innovation effect, cost effect, and barrier effect of environmental regulation can significantly promote the natural environment and resident health in the local city and the surrounding cities. The direct effect coefficient of environmental regulation was much smaller than the coefficient of environmental regulation in the non-spatial regression model of Column (1). If the non-spatial model is simply adopted, the spatial effects between variables will be overlooked, and the results will not be able to reflect the real transmission mechanism and mode of action among variables. Hence, hypothesis three was verified: the environmental pollution level and environmental regulation intensity of surrounding cities affect the resident health level of the local city.

4.3.3. The Analysis of Regional Differences in Spatial Effects

Compared with all the sample estimation results in Table 5, the spatial spillover effect of environmental regulation and environmental pollution of urban agglomerations in Table 6 has a poor significance on residents' health, which indicates that the spatial spillover effect between urban agglomerations is stronger than that of between cities within the urban agglomerations. In the CCZXUA, the direct effect, indirect effect, and total effect of environmental pollution and environmental regulation have all passed the significant test, which shows that the residents' health in this area is not only negatively affected by environmental pollution in their own city and surrounding cities, but also positively regulated by environmental regulation in their own city and surrounding cities. Furthermore, the indirect effects of environmental pollution and environmental regulation are less than the direct effects, which indicates that the spatial spillover effects of environmental pollution and environmental regulation in this region have less impact on residents' health than the local direct effects.

Table 6. The spatial spillover effects of environmental pollution and environmental regulation on residents' health in each region.

Variables	Effects	The Circum−Changsha −Zhuzhou− Xiangtan Urban Agglomeration	The Wuhan Urban Agglomeration	The Poyang Lake Urban Agglomeration
$lnEP$	Direct Effect	0.0791 * (0.0431)	0.0872 * (0.0495)	0.0104 ** (0.0052)
	Indirect Effect	0.0339 *** (0.0123)	0.1150 (0.0829)	0.0039 * (0.0021)
	Total Effect	0.0453 *** (0.0133)	0.2020 * (0.1120)	0.0143 ** (0.0071)
$lnER$	Direct Effect	−0.1480 * (0.0774)	−0.1400 ** (0.0663)	−0.0027 * (0.0014)
	Indirect Effect	−0.0626 *** (0.0201)	−0.1700 (0.1490)	0.0010 (0.0034)
	Total Effect	−0.0852 *** (0.0263)	−0.3100 ** (0.1570)	0.0037 (0.0114)
	Control variables	Yes	Yes	Yes
	Observation	88	110	110
	R^2	0.2101	0.1707	0.0050

The direct and total coefficient values of environmental pollution in WUA are positive, and the 10% significance test shows that environmental pollution in this area has a significant negative impact on residents' health. However, its indirect effect is not significant, which indicates that the spatial spillover effect of environmental pollution in this area has no significant impact on residents' health. This may be due to the fact that the spillover and diffusion of environmental pollution are closely related to the geographical distance, and the regression by urban agglomeration blocks the spillover of other urban agglomerations to the cities in this urban agglomeration and weakens the spatial spillover effect of environmental pollution. The direct effect and total effect coefficient values of environmental regulation are significantly negative at a 5% significance level, which indicates that environmental regulation in this region has a positive regulating effect on residents' health. Its indirect effect has not passed the significance test, which indicates that the spillover effect of environmental regulation in this region has no significant impact on residents' health.

Among the PLUA, the direct effect, indirect effect, and total effect of environmental pollution have all passed the significant test, which shows that the residents' health in this area is negatively affected by the environmental pollution of their own city and surrounding cities. The indirect effect is less than the direct effect, which indicates that the negative impact of environmental pollution in one's own city on residents' health is greater than the spillover effect of environmental pollution in surrounding cities on residents' health in one's own urban areas. The direct effect coefficient of environmental regulation is significantly negative, which indicates that environmental regulation in this region has a significant regulating effect on residents' health. The indirect effect of environmental regulation has not passed the significance test level; that is, the spatial spillover of environmental regulation in this region has no obvious impact on residents' health.

5. Robustness Test

In order to verify the reliability and stability of the research results, this paper analyzes the endogeneity of the model and the robustness of the empirical findings.

5.1. Endogeneity Test

The previous analysis shows that environmental pollution significantly inhibits resident health. However, resident health may also be affected by other unobservable factors. If such factors are ignored, the resulting endogeneity may lead to estimation bias. Thus, this paper employs an instrumental variable to process the endogeneity and obtain more reliable estimations. Drawing on the practice of Wang et al. (2018) [33], the endowment of mineral resources was taken as the instrumental variable of environmental pollution. Referring to China City Statistical Yearbooks, the paper measured the endowment of mineral resources in each city by the number of employees in the mining industry as a proportion of the total year-end population [34]. The design of the instrumental variable is very reasonable: the excavation of mineral resources and the combustion of ore energy are important sources of environmental pollution. In general, cities rich in mineral resources face serious environmental pollution. Yet the endowment of mineral resources does not directly affect mortality (resident health). Hence, the endowment of mineral resources is a satisfactory instrumental variable. Column (1) of Table 7 displays the regression results of the endogeneity test. After adding the instrumental variable, the regression coefficient of environmental pollution was significantly positive, which is in line with our expectations.

5.2. Robustness Test

(1) Lag effect. The impact of environmental pollution on resident health may have a lag effect. Hence, the explanatory variable (environmental pollution) was lagged by one period to regress model (1). According to the results in Column (2), Table 7, the coefficient of the lagged variable was significantly positive. This is consistent with the conclusion before the lagged variable. (2) Replacing some control variables. The proportion of the female population ($lnFP$), an important social variable, was added as a new control variable. Genetically speaking, women have a higher life expectancy than men. Hu and Peng (2018) demonstrated that the mean life expectancy of women across China is about 5 years longer than that of men [35]. Moreover, the number of certified (assistant) doctors per 1000 people was replaced by the number of urban employees participating in basic medical insurance ($lnIS$). The new variable can reflect the level of medical and health care to a certain extent. Yang et al. (2019) have pointed out whether participating in medical insurance affects the influence of different health indices [36]. Columns (3) and (4) in Tables 7 and 8 present the regression results after replacing the control variables for model (1), model (2), and model (3), respectively. The regression results again yield similar results, reflecting the overall reliability of our findings.

Table 7. Endogeneity test and robustness test on the health effect of environmental pollution and the regulating effect of environmental regulation.

Variables	(1) Endogeneity Test	(2) Introducing Lagged Explanatory Variable	(3) Replacing Control Variables	(4) Replacing Control Variables
$lnEP$	0.0939 ** (0.0457)	0.0339 ** (0.0157)	0.0282 * (0.0145)	0.0322 ** (0.0152)
$lnRGDP$	0.0640 * (0.0333)	0.0301 (0.0420)	0.0365 (0.0368)	0.0398 (0.0366)
$lnUB$	−0.0090 (0.0461)	0.0554 (0.0601)	−0.0010 (0.0619)	−0.0223 (0.0589)
$lnPL$	0.0292 *** (0.0102)	0.0240 *** (0.0090)	0.0163 * (0.0098)	0.0178 * (0.0102)
$lnED$	−0.0293 * (0.0171)	−0.0065 (0.0131)	−0.0158 (0.0123)	−0.0137 (0.0121)
$lnHC$	−0.0479 (0.0503)	−0.0832 ** (0.0366)		
$lnFP$			0.1393 (0.5646)	−0.1441 (0.5765)
$lnIS$			0.0109 (0.0122)	0.0121 (0.0122)
ER				2.3648 ** (1.0457)
$lnEP \times ER$				−0.2529 ** (0.1104)
Constant	−1.8886 *** (0.4800)	−1.2823 *** (0.3377)	−1.7151 (2.1939)	−0.6419 (2.2228)
Observation	308	308	308	308
R^2	0.3554	0.3899	0.3931	0.4116

Table 8. Robustness test on the spatial spillover effect of environmental pollution and environmental regulation.

Variables	(1) Estimation Coefficient	(2) Direct Effect	(3) Indirect Effect	(4) Total Effect
$lnEP$		0.0408 * (0.0217)	0.3715 *** (0.1320)	0.4123 *** (0.1427)
$lnER$		−0.0688 (0.0538)	−0.7869 *** (0.2765)	−0.8557 *** (0.2951)
$\boldsymbol{W}lnEP$	0.2660 *** (0.0928)			
$\boldsymbol{W}lnER$	−0.5927 *** (0.2000)			
$\boldsymbol{W}lnDR$	0.2398 ** (0.1188)			
Control variables	Yes	Yes	Yes	Yes
Observation	308	308	308	308
R^2	0.0550	0.0550	0.0550	0.0550

6. Conclusions and Policy Implications

This paper tries to explore the mechanism of environmental regulation and environmental pollution acting on resident health in China. We have used fixed-effects models and the spatial Durbin model with the panel data of 28 Chinese cities in the UAMYRY from 2009 to 2019 to extract robust findings. The main conclusions are as follows:

(1) Environmental pollution significantly suppresses resident health in the UAMYRY. The health effect of environmental pollution in the WUA is much more significant than that in the CCZXUA and the PLUA.

(2) Environmental regulation significantly weakens the negative effect of environmental pollution on resident health in the UAMYRY. There was a substitutive relation between environmental pollution and environmental regulation in the influence of overall resident health. Thus, suitable policies of environmental regulation can promote resident health and environmental quality. Regionally, the environmental regulation in the CCZXUA has the best effect on residents' health, followed by the WUA and the PLUA.

(3) Generally, the spatial spillover effect between urban agglomerations is stronger than that between cities in each urban agglomeration. As a whole, the UAMYRY shows that the spatial spillover of environmental regulation and pollution has a significant impact on residents' health, and the residents' health level is affected by both environmental pollution and environmental regulation of themselves and surrounding cities. From the perspective of regions, the spatial spillover of environmental pollution and environmental regulation in the CCZXUA has a significant impact on residents' health. The spatial spillover of environmental pollution and environmental regulation in the WUA has no significant impact on residents' health. Spatial spillover of environmental pollution in the PLUA has a significant impact on residents' health, while spatial spillover of environmental regulation has no significant impact on residents' health.

Drawing on the above conclusions, several suggestions were put forward for policymakers: Firstly, the UAMYRY should coordinate environmental management and establish a regional environmental collaborative management mechanism. The verification of hypothesis two indicates that the government should maintain the stability and adaptability of environmental regulation policies. The intensity of environmental regulation should be designed precisely and appropriately for specific regions. From the spatial spillover effect, the spatial spillover between urban agglomerations is stronger than the spillover effect between cities within each urban agglomeration; therefore, each region should break the concept of territory and strengthen the regional communication and collaboration. Promote the establishment of a collaborative cooperation mechanism for the UAMYRY to provide integrated management of environmental pollution problems and develop a long-term mechanism for pollution control and reduction. For example, the UAMYRY can set up an environmental supervision and cooperation mechanism to promote the joint solution to problems, the reasonable compensation for losses, as well as the collaborative policy-making, goal setting, policy implementation, and policy supervision between adjacent urban agglomerations.

Secondly, the CCZXUA should break through the inflection point of the intensity of environmental regulation and bring into play the radiation effect of environmental regulation. Although the intensity of environmental regulation in this region is relatively high and the regulation effect on residents' health is relatively significant, it is still necessary to break through the inflection point of the intensity of environmental regulation as soon as possible and ensure the significance of the rising stage. These measures would guarantee the quality and efficiency of UAMYRY's economic development in the long run. In addition, the spatial spillover effect of its environmental regulations has a significant impact on residents' health; therefore, the demonstration and diffusion effect of its environmental regulations should be given full play, with ecological priority and green development as the common goal. By optimizing regional resource allocation and improving ecological environment quality, an advanced model of urban agglomeration for ecological civilization construction should be created.

Third, the WUA should focus on combating environmental pollution and establishing a linkage mechanism within the urban agglomeration. The region's environmental pollution has the most significant impact on residents' health and should focus on solving the environmental pollution problems of the cities in the region through the flexible use of multiple policy instruments. The pollutant discharge must be restrained, and strict emission standards should be prepared, aiming to reduce pollution at the source and control pollution at the terminals. Furthermore, the intensity of environmental regulation in the region needs to be improved, and its spatial spillover effect should be enhanced. For example, the cities may also build an integrated ecological environment monitoring system to monitor the dynamics of industrial pollutant emissions and promote the interconnection of environmental information between cities. In this way, the cities will cooperate effectively in joint law enforcement and early warning response and perform well in cross-city and cross-sector responses to environmental emergencies.

Fourth, the PLUA should control the spillover effect of environmental pollution and strengthen the urban agglomeration's coordinated environmental management. This region's environmental pollution has a significant impact on resident health, and its environmental regulation has the worst regulatory effect. As a result, while strengthening environmental regulation, it is also necessary to strengthen coordinated environmental pollution treatment in urban agglomerations. This region should pursue collaborative development in environmental protection, economic growth, science, education, and health development and construct cooperation and mutual assistance mechanisms. For instance, the cities can establish an internal financial assistance system and a cross-city compensation system for ecological protection, make reasonable transfer payments for economic losses induced by environmental improvement, and strengthen the coordinated management of industrial pollution.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Adaptability test results of spatial metrology model.

Test	Statistic	*p*-Value	Test	Statistic	*p*-Value
LM–spatial lag	332.580	0.000	LR–spatial lag	43.87	0.000
Robust LM–spatial lag	13.007	0.000	Wald–spatial lag	13.42	0.037
LM–spatial error	329.212	0.000	LR–spatial error	45.36	0.000
Robust LM–spatial error	9.639	0.002	Wald–spatial error	13.22	0.040

References

1. Xie, Y.; Dai, H.; Hanaoka, T.; Masui, T. Health and economic impacts of PM2.5 pollution in Beijing-Tianjin-Hebei Area. *China Popul. Resour. Environ.* **2016**, *26*, 19–27. [CrossRef]
2. Shi, X. Promoting research on air pollution, climate change and population health under the goal of carbon neutrality and at the peak carbon dioxide emissions. *Chin. J. Dis. Control Prev.* **2021**, *25*, 1117–1119. [CrossRef]
3. Voorhees, A.S.; Wang, J.; Wang, C.; Zhao, B.; Wang, S.; Kan, H. Public health benefits of reducing air pollution in Shanghai: A proof-of-concept methodology with application to BenMAP. *Sci. Total Environ.* **2014**, *485*, 396–405. [CrossRef] [PubMed]
4. Xiong, Y.; Zou, Y.; Zheng, J.; Wang, Y.; Liang, X.; Tan, Y.; Fu, X.; Peng, X. Effects of haze on children's respiratory symptoms in Guangzhou. *J. Environ. Health* **2016**, *33*, 48–51. [CrossRef]

5. Bagula, H.; Olaniyan, T.; De, H.K.; Saucy, A.; Parker, B.; Leaner, J.; Röösli, M.; Dalvie, M.A. Ambient air pollution and cardiorespiratory outcomes amongst adults residing in four informal settlements in the Western Province of South Africa. *Int. J. Environ. Res. Public Health* **2021**, *18*, 13306. [CrossRef]
6. Tsan, Y.T.; Chen, D.; Liu, P.; Kristiani, E.; Nguyen, K.L.P.; Yang, C. The Prediction of Influenza-like Illness and Respiratory Disease Using LSTM and ARIMA. *Int. J. Environ. Res. Public Health* **2022**, *19*, 1858. [CrossRef]
7. Pan, L.; Ni, Y.; Xu, J.; Li, H.; Dong, W.; Yang, D.; Liu, Y.; Zhu, Y.; Shan, J.; Yang, X.; et al. Effects of outdoor and indoor $PM_{2.5}$ on exhaled biomarkers of patients with chronic obstructive pulmonary disease. *J. Environ. Health* **2016**, *33*, 1–4. [CrossRef]
8. Fan, Q.; Li, C.; Li, T.; Bai, X.; Zhao, Z.; Zhang, X. Effects of Air Pollutants on Respiratory Health in Junior High Schools in Taiyuan. *J. Shanxi Univ. (Nat. Sci. Ed.)* **2018**, *41*, 636–641. [CrossRef]
9. Chen, H.; Li, L.; Lei, Y.; Wu, S.; Yan, D.; Dong, Z. Public Health Effect and its Economics Loss of $PM_{2.5}$ Pollution from Coal Consumption in China. *Sci. Total Environ.* **2020**, *732*, 138973. [CrossRef]
10. Zhu, J.; Chen, L.; Liao, H. Multi-pollutant air pollution and associated health risks in China from 2014 to 2020. *Atmos. Environ.* **2022**, *268*, 118829. [CrossRef]
11. Li, M.; Du, W. Effects of Air Pollution on Residents' Health and Group Differences: An Empirical Analysis Based on CFPS (2012) Micro-survey Data. *Econ. Rev.* **2018**, *211*, 142–154. [CrossRef]
12. Li, X.; Gu, Z.; Xu, Y. The Impact of Public Environmental Appeals on Enterprise Pollution Emissions: Micro Evidence from Baidu Environmental Search. *J. Financ. Econ.* **2022**, *48*, 34–48. [CrossRef]
13. Lin, B.; Liu, H. Do Energy and Environment Efficiency Benefit from Foreign Trade?—The Case of China's Industrial Sectors. *Econ. Res. J.* **2015**, *5*, 127–141. Available online: https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFDLAST2016&filename=JJYJ201509011 (accessed on 12 September 2021).
14. Zhou, Y.; Hu, Q. Influences of environment regulation on environment pollution from the perspective of Hidden Economy: An analysis based on Zhejiang Province. *Urban Probl.* **2019**, *289*, 4–12. [CrossRef]
15. Zhang, G.; Zhang, Z.; Gao, Y.; Chen, Z.; Li, B.; Du, Y. Environmental regulation policies and public health: Based on the mediating effect test of environmental pollution. *Theory Pract. Syst. Eng.* **2018**, *38*, 361–373. [CrossRef]
16. Song, L.; Cui, F. Environmental Regulation, Environmental Pollution and the Health of Residents—The Analysis of Mediating Effect and Spatial Spillover Effect. *J. Xiangtan Univ. (Philos. Soc. Sci. Ed.)* **2019**, *43*, 60–68. [CrossRef]
17. Song, D.; Yang, Q.; Cheng, X. Does Environmental Regulation Improve Residents' Subjective Well-being: An Empirical Study of China. *Mod. Econ. Res.* **2019**, *445*, 7–15. [CrossRef]
18. Grossman, M. On the Concept of Health Capital and the Demand for Health. *J. Political Econ.* **1972**, *80*, 223–255. [CrossRef]
19. Cui, E.; Jiang, S.; Gu, S. Research on the Impact of Environmental Pollution, Commercial Health Insurance to Health Costs: Based on the Empirical Analysis of Provincial Panel Data. *Nankai Econ. Stud.* **2016**, *192*, 140–150. [CrossRef]
20. Zhao, Z. Health status and influencing factors of rural population in China. *Manag. World* **2006**, *22*, 78–85. [CrossRef]
21. Lu, H.; Qi, Y. Environmental Quality, Public Services and National Health: An Analysis Based on Cross-country Data. *Financ. Res.* **2013**, *39*, 106–118. [CrossRef]
22. Qi, Y.; Lu, H. Pollution, Health and inequality—overcoming the "Environmental Health Poverty" trap. *Manag. World* **2015**, *31*, 32–51. [CrossRef]
23. Ruan, F.; Zeng, X.; Duan, C. Influence of PM2.5 pollution on public health based on urban panel data. *China Environ. Sci.* **2020**, *40*, 5451–5458. [CrossRef]
24. Shi, D.; Ding, H.; Wei, P.; Liu, J. Can Smart City Construction Reduce Environmental Pollution. *China Ind. Econ.* **2018**, *32*, 117–135. [CrossRef]
25. Zheng, W.; Zhao, H.; Zhao, M. Is the development of digital finance conducive to environmental pollution control? Concurrently discussing the regulatory impact of local resource competition. *Ind. Econ. Res.* **2022**, *21*, 1–13. [CrossRef]
26. Yu, L.; Xue, D. Spatiotemporal change of urban green development efficiency in the Yellow River Basin and influencing factors. *Resour. Sci.* **2020**, *42*, 2274–2284. [CrossRef]
27. Huang, L.; Wu, C. Foreign Investment, Environmental Regulation and Green Development Efficiency of Cities along the Yangtze River Economic Belt. *Reform* **2021**, *37*, 94–110. Available online: https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFDLAST2021&filename=REFO202103008 (accessed on 15 September 2021).
28. Chen, S. Energy Consumption, CO_2 Emission and Sustainable Development in Chinese Industry. *Econ. Res. J.* **2009**, *44*, 41–55. Available online: https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFD2009&filename=JJYJ200904006 (accessed on 15 September 2021).
29. Tian, Z.; Dong, K.; Wu, F. Research on Total Estimates and Driving Factors of the End-use Energy Consumption's CO_2 Emissions in Jiangsu Province. *China Popul. Resour. Environ.* **2015**, *25*, 19–27. [CrossRef]
30. He, A.; An, M. Competition among local governments, environmental regulation and green development efficiency. *China Popul. Resour. Environ.* **2019**, *29*, 21–30. [CrossRef]
31. Zhang, L.; Cui, H. Impact of Urban Industrial Structure Optimization on Carbon Emissions of Urban Agglomeration in the Middle Reaches of the Yangtze River. *Reform* **2018**, *34*, 130–138.
32. LeSage, J.; Pace, K. *Introduction to Spatial Econometrics*; CRC Press: Boca Raton, FL, USA, 2009.
33. Wang, Y.; Hao, C.; Shi, M. Does Environmental Pollution Provoke Public Environmental Concern? *J. Financ. Econ.* **2018**, *44*, 106–124. [CrossRef]

34. Li, H.; Zou, Q. Environmental Regulations, Resource Endowments and Urban Industry Transformation: Comparative Analysis of Resource-based and Non-resource-based Cities. *Econ. Res. J.* **2018**, *53*, 182–198. Available online: https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFDLAST2018&filename=JJYJ201811012 (accessed on 24 October 2021).
35. Hu, Z.; Peng, X. Governance Choices in Dealing with China's Aging Population. *Soc. Sci. China* **2018**, *39*, 134–155. Available online: https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFDLAST2018&filename=JJYJ20181101 (accessed on 17 November 2021).
36. Yang, K.; Zang, W.; Li, G. The Impact of Adult Children's Education on the Health of Middle Aged and Elderly Parents. *Popul. J.* **2019**, *41*, 72–90. [CrossRef]